A COMPARISON OF THE OSHA MODIFIED NIOSH PHYSICAL AND CHEMICAL ANALYTIC METHOD (P&CAM) 304 AND THE DUSTTRAK PHOTOMETRIC AEROSOL SAMPLER FOR O-CHLOROBENZYLIDENE MALONITRILE

by

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DEDICATION

I dedicate this master's thesis to my mother, Janet, and my sisters, Amy, Lana and Stacy. These wonderful women extended continuous support and encouragement throughout the last 2 years. Without a doubt, I could not have completed this work without them.

Copyright Statement

ABSTRACT

A Comparison of the OSHA Modified NIOSH Physical and Chemical Analytic Method (P&CAM) 304 and the DustTrak Photometric Aerosol Sampler for O-Chlorobenzylidene Malonitrile

Monica Bradley, Master of Science Public Health, 2013

Thesis directed by: Commander Jennifer Gelker, Associate Professor, Preventative Medicine and Biometrics

The U.S. Army uses riot control agent o-chlorobenzylidene malononitrile (CS) for conducting mask confidence chamber training, which all U.S. Army recruits must complete. The effects of CS include pain/tearing of the eyes, upper respiratory track irritation, nasal irritation/discharge, salivation and burning of the skin. These effects are experienced by recruits as required tasks are completed (breaking the seal and completely removing the mask). Airborne and particulate CS levels are currently not measured with a real time monitor inside the mask confidence chamber. This study compared the non-specific, rapid photometric particle counting instrument, DustTrak, to the established OSHA modified NIOSH P&CAM 304 method to determine correlation between the two methods. Results were compared using paired t-test, correlation coefficient, and Bland-Altman limits of agreement. While the methods were found to be comparable ($p>0.05$), they showed weak positive association ($r = 0.03$). Additionally, the statistical comparison identified limits of agreement with large ranges about the mean (-29.7 to 20.5

mg/m³ (filter) and -13.1 to 13.3 mg/m³ (filter/tube)) relative to established occupational health limits and guidelines. Given the ACGIH-TLV of 0.39 mg/m³, and IDLH is 2 mg/m³, the limits of agreement suggest that the use of the DustTrak direct reading instrument to characterize CS concentrations during mask confidence chamber training may not be a reliable approach when attempting to provide an accurate characterization and reasonable margin of safety for human health. While not well correlated to the established, laboratory accepted standard for determining airborne CS concentration, the DustTrak instrument may potentially be well-suited to non-specific dusty environments.

The U.S. Army uses riot control agent o-chlorobenzylidene malononitrile (CS) for conducting mask confidence chamber training, which all U.S. Army recruits must complete. The effects of CS include pain/tearing of the eyes, upper respiratory track irritation, nasal irritation/discharge, salivation and burning of the skin. These effects are experienced by recruits as required tasks are completed (breaking the seal and completely removing the mask). Airborne and particulate mask confidence chamber CS levels are currently not measured with a real time monitor. This study compared the non-specific, rapid photometric particle counting instrument, DustTrak, to the established OSHA modified NIOSH P&CAM 304 method to determine correlation between the two methods. Results were compared using paired t-test, correlation coefficient, and Bland-Altman limits of agreement. While the methods were found to be comparable ($p>0.05$), they showed weak positive association ($r = 0.03$). Additionally, the statistical comparison identified limits of agreement with large ranges about the mean (-29.7 to 20.5 mg/m³ (filter) and -13.1 to 13.3 mg/m³ (filter/tube)) relative to established occupational health limits and guidelines. Given the ACGIH-TLV of 0.39 mg/m³, and IDLH is 2

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CHAPTER 1: Introduction

Background

Occupational exposures to aerosol-particulate matter have been in existence for centuries, and measures to control such exposures have long been practiced. Documentation dates back to the first century A.D. when Pliny described how boat painters used hoods to cover their heads in order to prevent inhalation of lead dust (30). More recent examples of occupational exposures to aerosol-particulate matter include coal mining that produces dust aerosols, and welding that produces very fine metal fume aerosols (17). Inhaled aerosol-particulate matter has many adverse health effects. It can cause damage to a person by accumulating in the upper respiratory tract causing illness, by depositing and damaging tissue locally, or by being dissolved and distributed systemically (17).

Military professionals have unique work environments and are often exposed to various potentially harmful aerosols-particulate matter depending on their occupation and deployments. Particulate matter exposures to environmental conditions in Iraq and Afghanistan, (e.g. burning trash, sandstorms, smoke from oil-well fires, and burning feces) were the most commonly documented concerns found in the medical records of veterans (25). Even for domestic training, military personnel can be exposed to harmful aerosol-particulate matter. This was the case for 20 soldiers that inhaled white smoke during a training exercise. The soldiers were in single file as they entered a tunnel when a smoke bomb accidentally discharged behind them (29). Inhaling aerosol-particulate matter from white smoke can cause respiratory tract damage (29), leading to chemical pulmonary edema and respiratory failure (21).

A further example of military training that exposes soldiers to harmful aerosol-particulate matter is mask confidence training. During this training U.S. Army recruits are exposed to o-chlorobenzylidene malononitrile (CS), which is an irritant agent and within seconds of exposure it can produce pain and burning of the mucous membranes and skin, pain and tearing of the eyes, and discomfort during respiration (32). Mask confidence training is essential and required training as it instills confidence in the protective ability of the protective mask for recruits. CS is thermally dispersed in a chamber (room) where recruits wearing military protective masks are required to complete various tasks, break the seal of their mask, speak, and completely remove their mask. Recruits instantly feel the irritating effects of CS when the seal of their mask is broken, and this reinforces the mask's capability to protect them against CS and other airborne chemical hazards (27).

The U.S. military has utilized CS for training since 1959, and to this date, every U.S. Army recruit has undergone mask confidence training with CS (10; 37). This training allows recruits to gain confidence in the capability of their military protective mask to guard against the effects of CS, as the irritating effects of CS to the eyes and lungs are not felt when there is a proper seal on the mask. A recruit's experience of confidence building during mask confidence training and the subsequent exposure to CS is necessary. Soldiers have the potential to work in environments where airborne chemical hazards are present, and knowing how to use one's protective equipment is crucial.

Although occupational exposure to CS is limited to select populations, mainly military and law enforcement, exposures to CS are regulated with occupational exposure

standards.   American Conference of Governmental Industrial Hygienists (ACGIH) suggests a threshold limit value ceiling (TLV-C) of 0.39 mg/m³.. The National Institute for Occupational and Safety Health (NIOSH) has a recommended exposure limit ceiling (REL-C) of 0.40 mg/m³ for CS, and the immediately dangerous to life and health (IDLH) concentration is 2.0 mg/m³(1; 35).

PUBLIC HEALTH SIGNIFICANCE

While there is beneficial value in mask confidence training, a recruit's exposure to CS when they break the seal of their protective mask, and when their mask is removed, is not regularly monitored. An Australian Defense Force (ADF) study found that the average concentrations of CS during two simulated confidence chamber training sessions were 5.8$\pm$0.6 mg/m³ and 5.3$\pm$0.7 mg/m³, and a peak concentration of approximately 15 mg/m³ was found for both training sessions. These results show that the average concentrations of CS were about 14 times greater, and the peak concentrations was up to 40 times greater than the TLV-C of 0.39 mg/m³ (32).

A further CS study was conducted by the U.S. Army, and it measured CS concentration levels inside a mask confidence chamber that simulated the U.S. Army training guidelines. This study found that the CS concentration exceeded the IDLH of 2.0 mg/m³ with the CS daily average concentration ranging from 2.33-3.29 mg/m³ (26). These two studies (ADF and U.S. Army) demonstrate how the CS concentrations during simulated training scenarios are exceeding the ACGIH TLV-C of 0.39 mg/m³, the NIOSH REL-C of 0.4 mg/m³, and the NIOSH IDLH of 2.0 mg/m³(1; 35). Due to the high concentrations and wide variability of the exposures, further exploration into the exact CS concentration values during actual U.S. Army recruit training is required. Additionally, research into instrumentation that has the capability of real-time monitoring

of CS concentrations during mask confidence training in an efficient and accurate manner is vital.

CS can be measured by a variety of instruments and methods. The ADF utilized a combination of instruments to measure the concentrations of CS during their study, specifically the DustTrak TSI Model 8520. The DustTrak instruments are data logging, battery operated, light scattering laser photometers that provide real time aerosol-particulate mass readings (31). The U.S. Army study employed the NIOSH physical and chemical analytical method P&CAM 304 for measuring concentration levels for the aerosol phase and vapor phase of CS.

RESEARCH OBJECTIVES

To date, no known studies have been conducted regarding a comparison study between the DustTrak and the P&CAM 304 method for quantifying CS concentration levels. Moreover, the historical research on CS concentration levels within CS confidence chambers have been completed as simulation studies , and were not conducted during actual mask confidence training (27) .

This study will compare a direct reading, non-specific photometric particle count instrument (DustTrak TSI Model 8533 Aerosol Monitor) to the established lab-based method specific for CS (OSHA modified NIOSH P&CAM 304) during actual mask confidence training for U.S. Army recruits. This research will also verify if the DustTrak is a suitable real time analyzer of CS during mask confidence training. Furthermore, this study will investigate if there is an increase in the CS concentration inside the mask confidence chamber throughout the duration of a training day, and if recruits undergoing mask confidence training are exposed to different CS concentrations depending on the sequence in which they complete their training.

There is a requirement to standardize the concentration level of CS that recruits are being exposed to in order to ensure that some recruits are not subjected to more of the irritating agent than others. Nine U.S. Marines developed transient pulmonary syndrome and were hospitalized after mask confidence training. Evidence suggests that the irritating effects of the CS had an association with vigorous physical exercise 36 to 84 hours after the exposure to CS (47). Recruit training is a time in a soldier's career of consistent strenuous exercise. CS particulate matter concentration levels not being monitored or standardized during mask confidence training is potentially putting the health of recruits at risk. The DustTrak could be implemented into the confidence chambers to monitor CS aerosol-particulate matter concentration levels, and increasing the safety of the training.

Chapter 2: Literature Review

Aerosols are liquid droplets or solid particles of microscopic size suspended in a gaseous medium, which is almost always air. Aerosols can range in size from visible dust in air, 50 μm in diameter or more, to microscopic particles that are invisible to the naked eye (17). Another term used to describe fine solids or liquid particles is particulate matter (PM). Particulate matter is often used when describing solids, while aerosol is more commonly associated with liquids. Like aerosols, particulate matter comes in a wide variety of sizes, and is often described according to the particle size. Particulate matter 2.5 ($PM_{2.5}$) has an aerodynamic diameter equivalent to or less than 2.5 μm, and is denoted as fine particulate, while particulate matter 10 (PM_{10}) has an aerodynamic diameter equivalent to or less than or equal to 10 μm but greater than 2.5 μm and is referred to as coarse particulate matter (20). Sources of aerosol-particulates include both anthropogenic and natural sources. Anthropogenic aerosols-particulates originate from automobiles and combustion industries in the form of smokes, dusts, fumes and mists. Naturally occurring aerosols include airborne dusts, clouds, mists, clay particles and sandstorms. Aerosol-particulates also include biological airborne particles, such as pollens, spores, viruses and bacteria (49).

While some aerosols may be used for beneficial purposes such as in an inhaler for asthmatics, there is a lengthy, documented history of aerosol-particulate related illnesses, including the occupational lung disease silicosis, the coal miner's black lung disease, and asbestos-related lung cancer (17). Aerosolized materials can directly affect the skin and eyes and can be absorbed through these routes. However, the aerosol-particulates that can be inhaled (PM_{10} to $PM_{2.5}$, and smaller) are the ones that are usually of primary

occupational health concern (17). Given this, it is the fine particulate ($PM_{2.5}$) that poses the greatest health risk because particles of this small size when inhaled can settle deeply in the lungs (20). Coarse particulate matter (PM_{10}) also poses a health concern as these particles can accumulate in the upper respiratory tract and may cause illness (20). Both $PM_{2.5}$ and PM_{10} can exacerbate illnesses in those persons with pre-existing medical conditions, and more than 150 epidemiology studies have demonstrated an association between fine particulate and acute mortality and morbidity (20).

An aerosol-particulate that can cause a variety of human health responses is O-Chlorobenzylidene Malononitrile (CS), which can be considered a fine or coarse particulate (or both) depending on the dispersal method. Thermal degradation of CS results in both fine and coarse particulate, while aerosol sprays normally results in fine particulate. CS is commonly referred to as tear gas and it is widely utilized as a Riot Control Agent (RCA) for controlling civil unrest and riots, as well as a challenge compound in military and law enforcement mask confidence training, and in personal protective sprays.

As previously stated, RCAs are used to control civil disturbances, and CS sprays were originally designed for police use to incapacitate violent offenders who could not be restrained without risk to life (51). A documented use of RCAs by law enforcement personnel began around 1910-1914 when ethylbromoacetate was used by French police against criminals. Some of these policemen joined the French army and used these munitions on the WWI battlefield and experienced some success with them (44). It was also during WWI when an estimated 30 different compounds were trialed for their irritant effects, but were often not successful (9).

CS was also present during the Vietnam War, where it was used extensively by the U.S. as a RCA (44). More recently, CS was used to control a case of civil unrest in Egypt in December 2012. Police fired CS tear gas at hundreds of protesters who gathered outside the house of Egypt's president, Mohammed Morsi (8). Presently, CS is used in mask confidence training for U.S. Army recruits and has been employed by the U.S. military training since 1959 (10).

CS is used by many Armed Forces, such as the U.S., Canada and Australia, for mask confidence training for their military members (3; 32). Every U.S. Army recruit is occupationally exposed to CS during initial mask confidence training and during refresher training in order to gain confidence in their M40 full-face, air-purifying protective mask (3). CS is a lachrymator and an irritant agent, and within seconds of exposure it can produce pain and burning of the mucous membranes and skin, pain and tearing of the eyes, and discomfort during respiration (32). This training allows recruits to gain confidence in the capability and effectiveness of their M40 protective mask to guard against the effects of CS, as the irritating effects of CS on the respiratory system and eyes are not felt when there is a proper seal on the mask.

The intended effect of all RCAs is the temporary disablement of people by intense irritation of the skin and mucous membranes (37). RCAs are frequently called harassing agents and irritating agents, and they produce their effects by sensory irritation, which causes extreme pain or discomfort to the affected organs (44). The eyes, skin, nose, and respiratory tract are the main organs affected. RCAs do produce temporary disability by way of their intense eye irritation and blepharospasm, which is the involuntary blinking or spasm of the eyelids, causing the eyes to close temporarily. Additionally, CS irritating

the airways leads to shortness of breath, coughing, and sometimes retching or vomiting (37). There are three main types of RCAs: sternutators, vomiting agents and lacrimators, and categorization is based on the physiological response the RCA elicit. Sternutators cause upper respiratory tract irritation and sneezing, vomiting agents induce vomiting, and lacrimators cause eye irritation and lacrimation, which is the secretion of tears (44).

RCA compounds have characteristics that are common to all, they have a sudden onset of effects from seconds to several minutes, and their effects last for a relatively brief duration of 30 minutes or less once removed from the exposure. CS does share these common characteristics with other RCAs, but the effects of CS are concentration dependent. Even for a low concentration exposure, symptoms will present themselves immediately, and usually dissipate 15 to 30 minutes after removal from exposure (13). RCAs also all have a high margin of safety, that is the ratio of the lethal dose, which is estimated, to the effective dose (44). The early RCAs, chloroacetophenone (CN) and chlorodihydrophenarsazine (DM), were replaced with CS and oleoresin of capsicum (OC), which are safer agents (37). CS replaced CN as the standard RCA for the U.S. Army, and was also taken on by most law enforcement agencies and militaries worldwide in the late 1950's. This change of RCA was due to the fact that CS happens to be more effective than CN, meaning it is less toxic, and causes effects at lower doses. The lower toxicity of CS means that its lethal concentration (LC50) is higher, which is the exposure that is lethal to 50% of the exposed people, and makes CS the safer choice for an RCA (44).

O-Chlorobenzylidene Malononitrile is referred to as CS because of the two chemists, Corson and Stoughton, who first synthesized CS in 1928 (16). CS has a molecular weight of 188.5 g/mol and a structural formula of $C_{10}H_5ClN_2$ (Figure 1) (44). CS in its natural state is a white crystalline solid with a pepper-like odor (46). It has a low vapor pressure, and is almost insoluble in water with a water solubility of 0.0002 mole/liter (7). However, CS is soluble in acetone, dioxane, methylene chloride, ethyl acetate, and benzene (42).

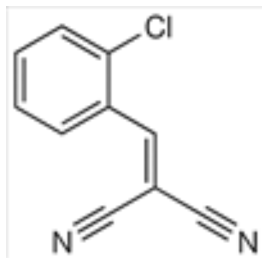


Figure 1 Molecular structure of CS

The odor threshold value for CS is 0.004 mg/m^3 (24). The human eye can detect CS at a concentration of 0.004 mg/m^3, and a concentration of 0.023 mg/m^3 is detectable in the airways. The National Institute for Occupational Safety and Health (NIOSH) has a Recommended Exposure Limit (REL) ceiling value for CS that should not be exceeded at any time which is 0.4 mg/m^3, and the concentration of CS that is immediately dangerous to life and health (IDLH) is 2 mg/m^3 (35).

Previous human research involving CS short-term exposure indicated that a concentration of 3.6 mg/m^3 was found to be intolerable to 50% of exposed people for 1 minute (IC50) (10). An additional study conducted by the U.S. Army's Directorate of Medical Research at Edgewood Arsenal (40) concluded that the LC50 for molten CS was 52,000 mg min/m^3 and 61,000 mg min/m^3 by thermal grenade. This document also

affirmed that the IC50 range is from 0.1-10 mg min/m³. Distribution of CS can be by explosive dispersion of a powder or solution, by dispersion of the powder when in a fine state, by releasing smoke by thermal means, or by spraying a solution (44).

During U.S. Army recruit mask confidence training, aerosolized CS is generated in the center of the chamber using a heat source. A hot plate acts as the heating source, and a coffee can is placed on top of the hot plate. Paper is ripped up and placed inside the coffee can, followed by the opening of CS capsules where granules of the CS are dispersed into the paper. CS is vaporized by the heat followed by condensation to an aerosol-particulate, and is assisted in dispersal throughout the chamber by fans (41). Recruits are exposed to the thermally dispersed CS when they are instructed to break the seal of their protective mask, speak, and completely remove their mask during mask confidence training (27).

In addition to exposures to CS occurring during military mask confidence training; law enforcement authorities in many countries also employ CS in some civil unrest situations. A variety of research into CS exposures and outcomes have been conducted involving dermal, ocular, oral, and inhalation studies in order to determine the toxicity of CS. The documented CS research involves many animal and human toxicology studies to CS exposure. Some of these studies will now be discussed.

ANIMAL TOXICOLOGY - DERMAL

Given the chemical characteristics of CS, the skin is a major route of exposure and the effects were observed in a 1978 animal study. This study involved 24 female rabbits, female guinea pigs, and male mice. All animals were given 12.5 mg of CS dissolved in corn oil or acetone in order to evaluate the skin effects of CS. Within 5 hours, this exposure to CS was observed to cause reddening of the skin (erythema), and

swelling due to the retention of fluid in the exposed area (edema). These dermal effects were reversible as they resolved within 7 days without any sloughing of the dead, outer layer of the skin (7).

HUMAN TOXICOLOGY - DERMAL

NIOSH's guide to chemical hazards has designated that CS has a skin notation, meaning that there is the potential for dermal absorption of this chemical in humans (14). Research on human dermal exposures to CS dates back to 1960, and exposure to CS can result in several cutaneous reactions, such as rashes, burns, blisters, and allergic contact dermatitis. Dermal effects to CS present themselves as a delayed stinging sensation, usually occurring several minutes post-exposure (10). The magnitude of the reaction depends on many factors including CS concentration, the method of CS dispersal, humidity and temperature (23). Several volunteers underwent patch test research in 1960 using a variety of different CS exposures to skin, such as exposure to pure CS solid, CS protected from air, CS in a porous gauze covering, CS (10% solution) in methylene dichloride, and CS (20% solution) in methylene dichloride (23). The 10% solution of CS in methylene dichloride did not cause a skin reaction in any of the volunteers. However, the porous gauze produced the greatest skin effects, and caused all volunteers to develop vesicles surrounded by erythema. While inside a wind tunnel the volunteers were subjected to a M18 grenade, CS-methylene dichloride spray, and CS-acetone spray, with the dispersed CS ranging from 0.5 μm, 1 μm, and 3 μm, respectively. Research volunteers reported burning on exposed skin areas, which increased in the presence of moisture. This burning sensation lasted for several hours and re-occurred when the affected skin was moistened (23).

It was in 1976 when research was conducted on 52 volunteers in order to study the effects of dilute solutions of CS on man. The 52 volunteers had their skin exposed to concentrations of CS ranging from 0.001 - 0.005% CS glyceryl triacetate by saturating bare skin and their clothes with the solutions. The effects on the skin displayed themselves as sunburn-like irritation, which started around the eyes and spread across the body, the extremities (feet and hands) were affected last. Ears and scalps of the volunteers were not usually affected. Even though there was the presence of soaked clothing, the skin effects did not last indefinitely and normally subsided after 10 minutes, despite not removing the clothing. Erythema was observed hours after the exposure, but vesication, edema desquamation was not observed in this study (7).

ANIMAL TOXICOLOGY - OCULAR

Exploration into the ocular effects of CS has been well documented, and like all RCAs, the eyes of both animals and humans respond to CS within seconds of exposure, and can have relatively long lasting effects even after removal of exposure has occurred. Research was conducted on rabbits to determine the acute ocular effects of CS. Solutions of 0.05 ml of 10% CS dissolved in methylene dichloride and 0.1 ml of 50% CS dissolved in methylene dichloride were administered to the left eye of several rabbits. A solution of 0.1 ml of just methylene dichloride was administered to the right eye of several rabbits, which resulted in no ocular reaction. Immediate conjunctivitis was observed in all of the rabbits' left eyes after the addition of the CS solution, where the conjunctivitis lasted for 30-60 minutes post exposure. The rabbits' left eyelids also presented erythema that lasted for 1-2 days. There was no permanent eye damage that resulted from the exposure (50).

Rabbits were the subjects of further research into the ocular effects of CS. In this study, investigators administered 5 mg and 10 mg of CS from a 10% methylene dichloride solution into the eyes of 20 rabbits. Again, conjunctivitis was instantly observed in the rabbits' eyes and cleared within a few hours after exposure. These findings are similar to those produced by Weimar et al, 1960 (50) . This study also administered 10 rabbits' eyes with 50 mg of CS in a 50% solution of methylene dichloride. This exposure did present similar results to that of the lower administered dose, and in both exposures permanent ocular damage was not produced (40).

HUMAN TOXICOLOGY - OCULAR

There is extensive research on the ocular effects of CS, many of which occurred during the early 1960s. A specific study took place inside a wind tunnel and exposed military and civilian volunteers to CS dispersed by CS-acetone spray (3 μm), CS-methylene dichloride spray (1 μm), and M18 grenade (0.5 μm). The eyes of all volunteers were instantaneously affected with a burning sensation that lasted 2 - 5 minutes, which then resulted in conjunctivitis that persisted for 30 minutes. Exposure immediately resulted in tearing of the eyes that lasted up to 15 minutes, and reddening of the eyelids was also experienced and continued for nearly an hour. Uncontrollable blinking did sometimes accompany the exposure and 5 - 10% of volunteers experienced photophobia, light sensitivity, that lasted for up to an hour. Additionally, some of the volunteers reported eye fatigue that remained for 24 hours post exposure (23).

A 1963 study consisted of six volunteers that had only their eyes exposed to large and small CS particles in order to assess the effects of CS particle size on the human eye. Volunteers were exposed to large and small CS particles while inside a wind tunnel. The small particles were dispersed from a 2% CS solution in methylene dichloride that

resulted in a mass median diameter of 0.9 μm. The large CS particles were generated from an assembly using a spray system atomizing nozzle fitted with a powder hopper giving a median diameter of 60 μm. All six volunteers exposed to the large particles were able to tolerate the 60 second exposure, while only two of the five volunteers could tolerate the 60 second small particle exposure. All volunteers experienced visual difficulties after the exposure, and recovery time for the larger particles was 4.67 minutes and 1.5 minutes for the smaller particles. It was determined that small particles produced eye irritation much quicker than the larger particles; though, the larger particles prolonged the effect on the eye (38).

ANIMAL TOXICOLOGY - ORAL

A 1978 study researched the oral effects of CS on various animals. CS in polyethylene glycol was administered by a catheter into the stomach of rabbits, rats and guinea pigs. Male rabbits had a dose range of 100 - 250 mg/kg with a LD50 of 231 mg/kg, and female rabbits had a dose range of 75 - 400 mg/kg with a LD50 of 143 mg/kg. Male rats were given doses between 500 - 1590 mg/kg with a LD50 of 1366 mg/kg, while female rats had dose ranges of 629 - 1588 mg/kg and a LD50 of 1284 mg/kg. Only female guinea pigs were administered CS, with a dose range of 119 - 300 mg/kg and a LD50 of 212 mg/kg (7). The amount given to the animals was equal to about half of the LD50 for each species, and a single dose of that amount of CS did not result in diarrhea or gastric mucosa damage as compared to controls (46). Repeated exposure of the animals with CS did not cause detectable lesions in liver, lung, spleen, kidney, pancreas or adrenal gland (7).

A further experiment on animal ingestion of CS was conducted on rabbits where they were given CS contaminated bread to eat. Four hours after exposure, the rabbits had

no stomach damage that was attributable to CS (33). A contrasting study did find that animal ingestion of CS can cause damage to the stomach. CS levels equaling the LD50 for each species were administered to the animals, and showed that CS had the ability to result in gastroenteritis and intestinal perforation when administered at these high doses. Toxic signs were observed 2 - 4 hours after exposure and were displayed in the form of tremor, pilo erection, and increased salivation (7).

HUMAN TOXICOLOGY - ORAL

There is documentation of intentional and accidental human ingestion of CS; however, there is no record of any controlled studies researching the oral effects of CS on humans. CS was intentionally ingested during a suicide attempt of a young male. The individual was treated with high amounts of saline cathartics, and suffered from diarrhea and abdominal cramps, but he did make a full recover (37). A case of accidental CS ingestion happened when a male took an 820 mg CS pellet because he thought it was a vitamin. The man was treated with viscous lidocaine and liquid antacid, and was given droperidol intravenously. The man had a full recovery; however, he did vomit twice and had six watery bowel movements (37).

Another case of accidental human ingestion of CS took place in central Israel in 2003. Seven people accidentally consumed CS contaminated juice where investigators discovered several small pellets of CS partially dissolved at the bottom of a communal juice container. Five of the seven people presented within minutes to the primary care clinic of their workplace complaining of headache, eye tearing and irritation, burning of the throat and mouth, and facial irritation. The two remaining people who ingested the CS contaminated juice went to the clinic the following day with abdominal pain, nausea and diarrhea. When the seven people were questioned, they reported the burning

sensation did not immediately occur after consumption of the contaminated juice, but presented itself minutes later (46). This information is consistent with the 1972 research by Kemp and Wilder, where they found that people who ingested CS contaminated sugar did not experience symptoms for 30 seconds post exposure (33). The onset of symptoms being delayed is ascribed to the sweetness of sugar masking the effects of CS (33). All seven of the people were under observation for 24 hours and then discharged, and the amount of CS ingestion was approximated to be less than 25 mg, far less than the lethal amount for a 70 kg man (approximately 14 g). It was determined by the author that it might not be possible for a human to consume a lethal amount of CS due to the local irritation caused by the compound (46).

ANIMAL TOXICOLOGY - INHALATION

Several inhalation studies were conducted to evaluate the acute toxicity of CS, and studies do show that the toxic effects of CS vary depending on how the CS is dispersed (6; 7; 50). It was Weimar et al's research that discovered that the molten aerosol dispersion of CS resulted in higher lethality than dispersion of CS in methylene dichloride. It was also revealed that methylene dichloride has a higher lethality than dispersion of CS by thermal grenade (50).

An inhalation study involving 30 rats and 5 dogs exposed the animals to molten CS aerosol that was dispersed by an oil bath in a 200 L exposure chamber. Both the rats and dogs were exposed for 5 days a week for a 5 week period; however, the exposure time per day did vary. Rats were exposed daily for 5 minutes (3,600 mg min/m^3), which resulted in a cumulative dose of 91,000 mg min/m^3. Concerning the rats, 6 out of the 30 did die during the 5 week period; however, there were no gross pathological changes found in these rats or the other rats sacrificed once the study concluded. Dogs were

exposed daily for 1 minute (680 mg min/m^3) and resulted in a cumulative dose of 17,000 mg min/m^3. There was a clinical response to the CS exposure for the dogs, and it presented itself in the form of salivation. Though, the salivation did resolve itself one minute after the CS exposure. The rats and dogs both did not show significant differences from controls in heart, lungs, kidney, spleen, liver or body weight ratios (39).

HUMAN TOXICOLOGY - INHALATION

CS in the form of a vapor, aerosol or solid can be inhaled into the respiratory tract and can cause health effects. CS in low concentrations does irritate the pulmonary tract, and at high concentrations of CS the respiratory system is affected (37). One inhalation study exposed volunteers to several concentrations of CS by total body exposure and by a facemask to determine what CS concentration would be intolerable. The concentration of CS was varied from 2 - 360 mg/m^3 with the exposure time ranging from 30 seconds to 120 seconds. At exposure to CS, the volunteers experienced irritation of the nose, throat and chest, accompanied by breathing difficulties and coughing. However, airway resistance did not significantly change from the exposure. The volunteers' health effects resolved within minutes of being removed from exposure. It was discovered that 50% of the volunteers found CS intolerable at concentrations of 10 - 20 mg/m^3 (22).

DUSTTRAK PHOTOMETRIC AEROSOL SAMPLER

The DustTrak is a real-time aerosol and particulate monitor that measures contaminants such as dust, smoke, fumes and mists. This device is designed to conduct monitoring in industrial workplaces, office settings, and construction and environmental sites (31). It has been used to monitor occupational exposures for boilermakers (34), particulate matter levels in iron foundries (15) and indoor microenvironments of schools (12).

A study was conducted comparing two different methods for measuring fine particulates, $PM_{2.5}$ was sampled using a filter-based gravimetric sampling method and the direct-reading instrument, DustTrak 8520 aerosol monitor (34) . Both of these sampling methods were utilized to determine the $PM_{2.5}$ exposure for boilermakers exposed to welding fumes and residual fuel oil ash. This study found that $PM_{2.5}$ measurements from the DustTrak were well correlated and fairly predictive of measurements from the gravimetric sampling methods for aerosols in the boilermakers' work environment. Results from this study did suggest that aerosol-particle characteristics may affect the relationship between the gravimetric and DustTrak $PM_{2.5}$ measurements (34).

Research was conducted on the comparison of two real-time dust monitors, the DustTrak 8520 aerosol monitor, and the Grimm Series 1.108 aerosol spectrometer. Both monitors were used to determine PM_{10} and $PM_{2.5}$ levels simultaneously in an iron foundry (15). A gravimetric method was also used during this study as a reference method to compare the two real-time dust monitors to. The DustTrak's response to PM levels was higher than that of the aerosol spectrometer. The DustTrak also provided an overestimation of PM levels; while the aerosol spectrometer measured PM levels lower than the actual concentrations (15).

Chapter 3: Materials and Methods

The comparison study between the DustTrak and the OSHA modified NIOSH P&CAM 304 sampling method for measuring the aerosol and vapor phase of CS was an observational study. CS concentration sampling was taken during mask confidence

chamber training for U.S. Army recruits, and at no time was there interference in standard operating procedures for the mask confidence chamber by a researcher.

MATERIALS

DustTrak 8533 DRX Aerosol Monitor

DustTrak (TSI Incorporated, Shoreview, MN, USA) is a data logging, battery operated, 90° light-scattering laser photometer that provides direct aerosol mass readings (Figure 2). It uses a sheath air system that isolates aerosols in the optics chamber of the instrument (31). The DustTrak can simultaneously measure size-segregated mass fraction concentrations corresponding to total PM fractions, PM_{10}, $PM_{2.5}$, and PM_{1}. It combines both single particle detection and particle cloud, which is the total area of scattered light, in order to achieve mass fraction measurements (31).

The DustTrak has an aerosol concentration range of 0.001 to 150 mg/m^3, operational temperature of 32 to 120 °F (0 to 50 °C), and an operational humidity of 0 to 95% relative humidity (31). It has an adjustable flow rate, which for this study was programmed to flow at a rate of 1.5 liters per minute. It also has an adjustable log interval, the amount of time between logged data points (1 second to 1 hour), which was adjusted to log data points every five seconds. Two DustTraks will be involved in this research, DustTrak A and DustTrak B. Both DustTraks are the same model, and were rented for the duration of the study.

Figure 2 – DustTrak DRX 8533 Aerosol Monitor

Sampling Pumps, Media, Calibrator

Personal sampling pumps, AirChek XR5000 (SKC, Eighty Four, PA, USA), with a flow rate of 1.5 liters per minute were used in this study for the OSHA modified NIOSH P&CAM sampling (45). The sampling media consisted of OSHA Versatile Sampler (OVS-Tenax) - 13 mm Tenax Tube (140/70 mg sections) with enclosed glass fiber filter (36). The Defender 510 was used to calibrate both the AirChek XR5000 sampling pumps and the DustTraks (19)

CS Capsules

Ft Jackson provided all CS capsules utilized in this study. The capsules were 96% pure CS, and they were procured through the regular military ordering system.

METHODS

DustTrak

The DustTrak Aerosol Monitors were factory calibrated before the sampling period began, and both DustTraks A and B were zero calibrated before each sampling day. The DustTraks were manually turned on and remained on throughout the duration of the sampling day until they were manually turned off. The DustTraks were secured to music stands daily, and placed inside the chamber at their respective positions. Figure 8

shows the location of DustTraks A and B. The instruments were left on until the last platoon finished their mask confidence chamber training. An average of three hours of recorded data was logged daily by the DustTraks and was downloaded every night to a laptop computer using the TrakPro Data Analysis Software.

OSHA Modified NIOSH P&CAM 304

For the OSHA modified NIOSH P&CAM 304 method the maximum volume is 90 liters, the maximum flow rate 1.5 liters per minute, and the maximum time is 15 minutes (36). To ensure the method was strictly followed, the sampling pumps were calibrated to 1.5 liters per minute pre and post mask confidence chamber training using the Defender 510. The pumps operated for approximately 10 minutes, which is the average length a platoon takes to complete mask confidence chamber training. After the 10 minutes of sampling finished, the sampling trains were removed, caped, sealed in individual one liter plastic bags, and placed into a cooler. Another pre-assembled sampling train will then be placed on the pump and sampling will continue as previously described for the next platoon. This procedure was repeated until all soldiers had proceeded through the chamber (28). Additionally, the CBRNE NCO wore a personal sampling pump and sampling train, with the pump being placed in their pant pocket, and the sampling media was attached to their jacket at the respiration zone. The CBRNE NCO pump and sampling train ran for the entire duration that the CBRNE NCO was in the mask confidence chamber. A 15-minute background sample was taken at the beginning of each training day with both DustTrak and the OSHA modified NIOSH P&CAM 304 method. All samples were sent to the United States Army Public Health Command (USAPHC) for analysis, with the analytical solvent consisting of 20%

methylene chloride in hexane, and the analytical method being high performance liquid chromatography/ultraviolet analysis (HPLC/UV) (36).

Confidence Chamber Description and Procedures

CS aerosol- particulate concentration sampling was conducted at Fort Jackson, a U.S. Army Base located in Columbia, South Carolina. The chamber used for the mask confidence training and CS concentration sampling was the PFC Arthur C. Jett Chemical Biological Radiological Nuclear Explosive (CBRNE) Range (Figure 3). Mask confidence chamber training for U.S. recruits occurs at Fort Jackson 3 to 6 times a week, Monday through Saturday, on a year round basis. Every day that mask confidence chamber training occurs, 1 to 2 companies will complete the training. A company is made up of four platoons, with each platoon consisting of 45 to 60 soldiers, resulting in every company having 180 to 240 soldiers. A company has approximately 8 Drill Sergeants (DS), and during mask confidence chamber training 5 to 6 DS will accompany each platoon as they complete their training. In addition to the DS staff inside the chamber, a Chemical Biological Radiological Nuclear Explosive (CBRNE) Noncommissioned Officer (NCO) is also present at all times, and it is the CBRNE NCO who is in charge of dispersing the CS for the training. Each training session for respective platoons lasts on average 8.24 minutes.

The experimental duration of sampling was from 15 August to 14 September 2012, with sampling occurring on 16 of those days. During this sampling period, the temperature and relative humidity remained relatively constant with the average temperature being 82.3 F (27.9 °C), with a low of 74.7 F (23. 7°C) and a high of 84.4 F (29.1°C), and the average relative humidity being 72.2%.

Figure 3 - PFC Arthur C. Jett Chemical Biological Radiological Nuclear (CBRN) Range

The dimensions of the mask confidence chamber are 13.11 meters in length and 7.32 meters wide. There are two doors at the entrance way that recruits use to enter the chamber. There are three doors at the exit way of the chamber; however, only two of the doors are utilized for exiting the chamber. Both the entrance and exit doors are double doors with metal frames, and have vertical-hanging plastic strips that recruits walk through in order to get into or out of the chamber.

The CS generating station is situated at the center of the chamber, 6.55 meters from both the entrance and exit ways and 3.66 meters from either wall. The OSHA modified NIOSH P&CAM 304 sampling station was set up 1.22 meters from the CS generating station towards the exiting side of the chamber. DustTrak A was also set up towards the exiting side of the chamber and located at a distance of 1.52 meters from the CS generating station. DustTrak B was located 1.52 meters away from the CS generating station towards the entrance way of the chamber and 3.05 meters away from DustTrak A (Figure 4). The DustTrak instruments were placed and secured on music stands at a height of 134.6 centimeters, and the OSHA modified P&CAM 304 sampling media was

placed at a height of 134.6 centimeters. Both DustTraks and all of the OSHA modified NIOSH P&CAM 304 sampling media were located in the respirable zone (Figure 5).

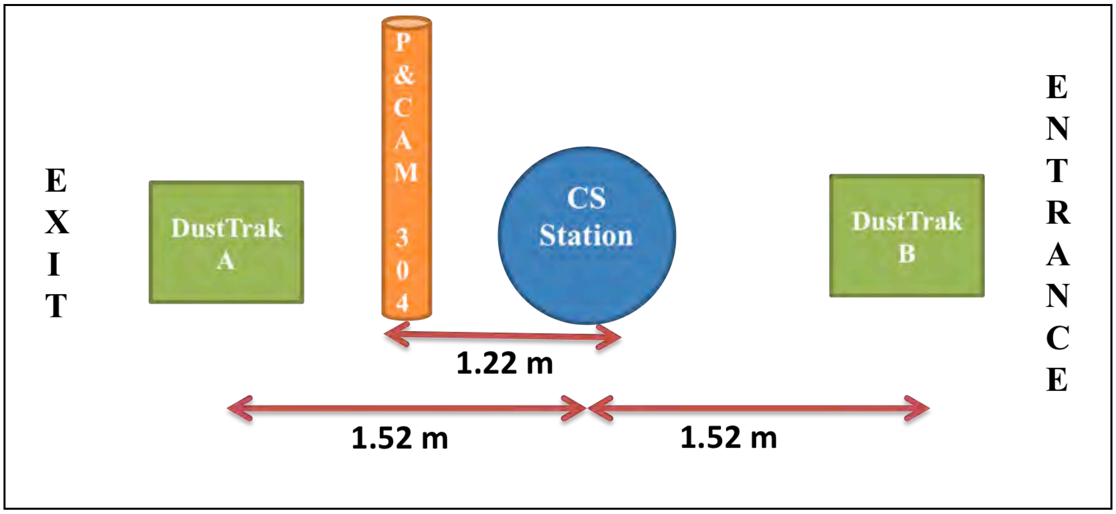


Figure 4: Schematic of sampling set-up inside mask confidence chamber

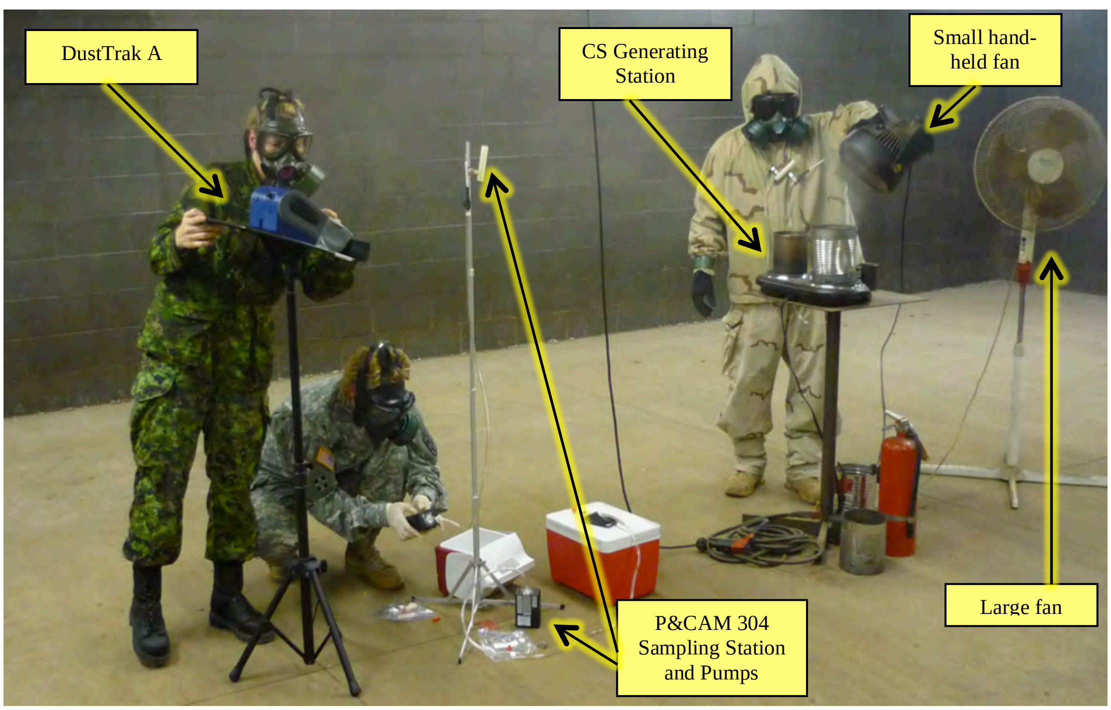


Figure 5: Sampling set-up inside the mask confidence chamber

Before mask confidence chamber training commences, the CBRNE NCO will charge the chamber with 10 CS capsules, and this procedure can take 10 to 20 minutes (4). Recruits are not allowed inside the chamber while it is being charged, and the chamber doors are kept closed during this process. CS will continue to be generated throughout the duration of mask confidence training, and the CBRNE NCO will burn 6 additional CS capsules for every platoon that enters the chamber (2). Aerosolized CS was generated by using a hot plate as the heating source, and a coffee can was placed on top of the hot plate. Paper is ripped up and placed inside the coffee can to assist in the burning of the capsules, capsules are then opened up and the granules of the CS are dispersed into the paper (Figure 6). CS is thermally combusted, generating both vapor and an aerosol and is assisted in dispersal throughout the chamber by one large stationary fan and one small hand-held fan (41). The large stationary fan was located 0.91 meters from the CS generating station towards the entrance way of the chamber and the small handheld fan was kept at the CS generating station and used periodically by the CBRNE NCO to disperse the CS towards the recruits (Figure 5).

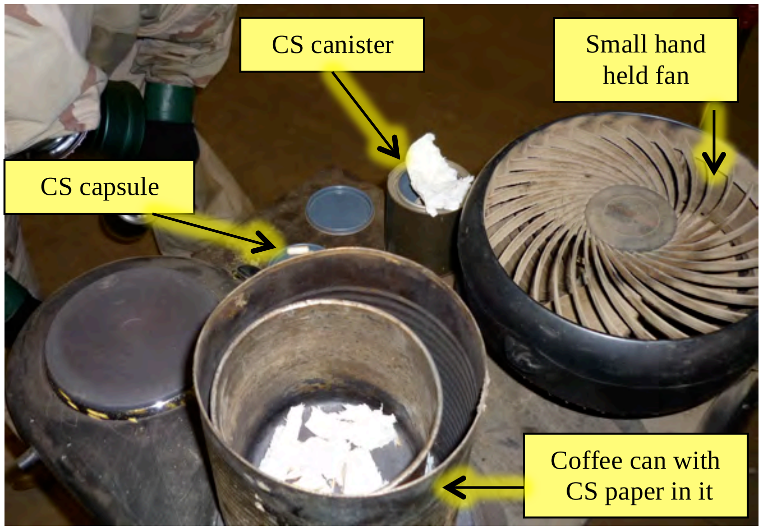


Figure 6: CS generating station

A company will line up by platoons outside of the entrance way of the mask confidence chamber (Figure 7). It is at this point where the recruits are instructed to don their M40 protective masks, which is the standard personnel protective equipment (PPE) worn by all personnel entering the mask confidence chamber. The M40 is a standard issue, full-face, air-purifying protective mask equipped with a combination vapor/particulate filter canister, which provides respiratory, eye and face protection against chemical and biological agents, radioactive fallout particles, and certain toxic industrial contaminants (5). CBRNE NCOs will check recruits' M40 protective masks for function, fit and proper seal prior to movement into the confidence chamber.

Figure 7:– Recruits lining up in platoons outside the mask confidence chamber

One platoon enters the mask confidence chamber at a time and will remain inside for approximately 10 minutes. The doors to the chamber remain closed during the exercise, except when platoons enter and exit. It can take between 60-90 minutes for all four platoons in a company to complete mask confidence chamber training. Once inside the chamber, the recruits are instructed by their drill sergeants to line up against the walls

and to complete a series of tasks, to include breathing normally with the M40 mask, chewing movements, moving the head side to side, and running in place (Figure 8). The drill sergeant then instruct the recruits to break the seal of their protective masks and state their full names and identification number and then reseal their M40 mask. It is at this point where the drill sergeant staff will instruct 20 recruits, 10 on each side of the chamber, near the exiting end, to completely remove their protective masks, place them in their mask carriers around their waists, and state the Soldier's Creed (Figure 9). This last exercise lasts between 17-128 seconds, and varies depending on the reaction of recruits during the exercise.

Figure 8: Recruits lining up against the wall inside the mask confidence chamber

Figure 9: Recruits removing their M40 protective masks and reciting the Soldier's Creed

When the group of 20 recruits has completed this final exercise they are then allowed to exit the mask confidence chamber through the two exiting doors. The total time within the chamber averaged approximately 10 minutes per platoon. When the recruits exit the chamber, drill sergeant staff is on the outside waiting for them, and instruct the recruits to flap their arms, keep their eyes open, and to walk away from the chamber. Recruits will then be checked off by the drill sergeant staff confirming that they completed their mask confidence chamber training (Figure 10). The mask confidence chamber training procedures outlined above are specific to Fort Jackson, but are similar to other U.S. Army Basic Training Chamber Exercises (2).

Figure 10 - Recruits post mask confidence chamber training

Comparison Study – Research Aim 1

For the comparison study between the DustTrak and OSHA modified P&CAM 304, a sample represents a platoon's CS concentration average from its mask confidence chamber training session or the CS concentration from the CBRNE NCO's personal exposure sampler. For the P&CAM 304 method, pre-assembled sampling trains were used to collect samples for every platoon and were switched out after each platoon

completed their training session. P&CAM 304 samples were stored in a cooler until they were shipped to the United States Army Public Health Command (USAPHC) for analysis. The time it took a platoon to complete mask confidence chamber training was recorded. These recorded platoon training times were then used to extrapolate the concentration readings from the DustTrak, as the DustTrak continuously logged data during the mask confidence chamber training sessions.

The comparison study for the two methods of measuring CS had a two case approach. Case 1 was to compare the DustTrak to the entire P&CAM 304 method. Each platoon's CS concentration average and CBRNE NCO personal sampler CS concentration from the DustTrak were compared to the CS concentration values from both the vapor phase (tenex tube) and aerosol-particulate phase (filter) from the P&CAM 304 method. Case 2 was similar to case 1 as it involved the comparison of all samples from the DustTrak and P&CAM 304, except that the CS concentration averages from the DustTrak were only compared to the CS concentration from the aerosol-particulate phase (filter) of the P&CAM 304. Case 2 was conducted because the filter portion of P&CAM 304 and the DustTrak were measuring the same phase of CS. An assumption of the research project prior to the observational study was that the only aerosol-particulate inside the mask confidence chamber was CS.

Accumulation Study – Research Aim 2

DustTrak A and DustTrak B ran continuously during mask confidence chamber training and logged concentration measurements the entire time (every 5 seconds). For both DustTraks (A and B), the CS concentration measurements for platoon 1, platoon 2, platoon 3 and platoon 4 were ranked in order of lowest CS concentration to highest CS concentration. The ranking of platoons from lowest to highest CS concentration was

done for every company that completed mask confidence training during the sampling period. The CS concentration results from P&CAM 304 were also used to rank the platoons in a company from lowest to highest CS concentration level. This was done as the OSHA modified NIOSH P&CAM 304 method of sampling is the gold standard and a validated method for sampling and measuring CS concentrations.

Statistical Analysis

The sample size for the comparison study between the DustTrak and the NIOSH P&CAM 304 was 74, and samples were platoon concentrations to CS and the CBRNE NCO personal sampler CS concentrations. The statistical analysis performed on this data was a paired t-test, the correlation within means, and the Bland-Altman difference against means.

The paired t-test is used to compare two population means where there are two samples in which observations in one sample can be paired with observations in the other sample and the differences need to be approximately normally distributed (43). In this study, the two population means were the CS concentration results from the DustTrak and the P&CAM 304,and samples from the DustTrak are paired with samples from the P&CAM 304.

The correlation coefficient (r) was determined between the two sampling methods, DustTrak and P&CAM 304, in order to measure the strength of a relation between the two methods. However, a high correlation does not mean that the two methods agree. As previously stated, correlation measures the strength of a relation between two variables, not the agreement between them. Perfect agreement can be had if the points in the graph lie along the line of equality, but there will be perfect correlation if the points lie along any straight line (11). This is why the Bland-Altman Plot was also

conducted, to assess the agreement between the DustTrak and P&CAM 304. The Bland-Altman Plot is used to compare two measurement methods where the differences between the two methods, in this case DustTrak and P&CAM 304, are plotted against the averages of the two methods (11). Limits of agreement are determined from the Bland-Altman Plot, and a graphical representation of the agreement between the two measurement methods is given.

The sample size for the CS accumulation study was 60, and samples were platoon group CS concentrations. The statistical analysis conducted on the data from DustTrak A, P&CAM 304, and DustTrak B was the Kruskal-Wallis Test. The Kruskal-Wallis Test is a one-way analysis of variance by ranks, and it is the statistical tool to use over the one-way analysis of variance when the populations from which the samples are drawn are not normally distributed with equal variances, or when the data for analysis consist only of ranks (18). The accumulation study ranks each platoon in a company according to CS concentration (lowest to highest), and was the rationale behind selecting the Kruskal-Wallis Test.

CHAPTER 4: Results

Table 1 displays the daily CS concentration mean for each company (average CS concentration from all 4 platoons). Table 1 values are displayed for each sampling method, DustTrak A, DustTrak B, P&CAM 304 (filter and tube) and P&CAM 304 (filter) and the values excluded the CBRNE NCO's personal sampler results. The sample column in Table 1 represents the date in which a company completed mask confidence training. When two companies completed mask confidence training on the same day, they were designated as company (A) or company (B).

Table 1. Daily CS Concentration Mean for each Company (mg/m^3)

Sample (Company)	**DustTrak A**	**P&CAM 304**(filter/tube)	**P&CAM 304**(filter)	**DustTrak B**
15/08/12	15.7	16.2	6.35	8.7
16/08/12	9.0	7.23	1.083	7.8
17/08/12	11.8	12.5	0.638	12.5
18/08/12	5.7	5.79	0.036	6.9
20/08/12	8.91	29.0	21.9	2.75
22/08/12 (A)	4.18	21.5	0.33	3.20
22/08/12 (B)	2.88	4.82	1.09	2.40
24/08/12	38.1	6.95	0.003	30.9
27/08/12	3.69	5.87	0.039	4.90
29/08/12 (A)	3.24	2.44	0.002	3.30
29/08/12 (B)	2.17	2.06	0.001	2.70
5/09/12 (A)	5.59	3.80	0.002	6.00
5/09/12 (B)	6.65	3.52	0.010	6.00
7/09/12 (A)	7.51	4.02	0.014	7.20
7/09/12 (B)	5.41	7.67	0.129	5.80
11/09/12	8.95	6.49	1.583	7.20
12/09/12 (A)	11.2	5.50	3.225	9.00
12/09/12 (B)	6.67	9.29	3.457	6.50
14/09/12	10.4	6.74	0.165	9.30

The CS concentration average for all companies was 8.83 mg/m³ for DustTrak A, with a maximum concentration average of 38.1 mg/m³ and a minimum average of 2.17 mg/m³. The CS concentration average for all companies for P&CAM 304 (tube and filter) was 8.49 mg/m³ (maximum at 29 mg/m³, minimum at 2.06 mg/m³) and 2.11 mg/m³ for P&CAM 304 (filter) (maximum at 21mg/m³, minimum at 0.001 mg/m³). DustTrak B had a CS concentration average for all companies of 7.53mg/m³, with a recorded maximum concentration average of 30.9 mg/m³ and minimum of 2.4 mg/m³.

Table 2 consists of results from samples collected within the mask confidence chamber during a single day of sampling, 29 August 2012, with DustTrak A and P&CAM 304 (filter and tube). Each row in Table 1 represents area sampling results for a respective platoon completing their mask confidence training or the CBRN NCO's personal sampling results. Displayed are the daily CS concentration averages for DustTrak A, and the Tenax tube and fiber filter samples for P&CAM 304, which is case 1 of the comparison study. DustTrak A and P&CAM 304 (tube and filter) values are also given in Log10, which was necessary due to extreme outliers in CS concentration averages reported by both the DustTrak and P&CAM 304 throughout the sampling period, 15 August to 14 September 2012. Information on the daily CS concentration averages for all sampling days can be found in Appendix A.

Table 2. CS Concentration Averages with DustTrak A and P&CAM 304 (tube/filter)

Sample	**DustTrak A Daily CS Avg mg/m³**	**P&CAM 304 Daily CS Avg (tube/filter) mg/m³**	**DustTrak A Daily CS Avg mg/m³ Log10**	**P&CAM 304 Daily CS Avg (tube/filter) mg/m³ Log10**
29/08/2012 Plt 1	3.03	3.34	0.48	0.52
29/08/2012 Plt 2	3.97	2.58	0.60	0.41
29/08/2012 Plt 3	3.31	2.18	0.52	0.34
29/08/2012 Plt 4	2.64	1.67	0.42	0.22
29/08/2012 NCO	2.95	1.03	0.47	0.01

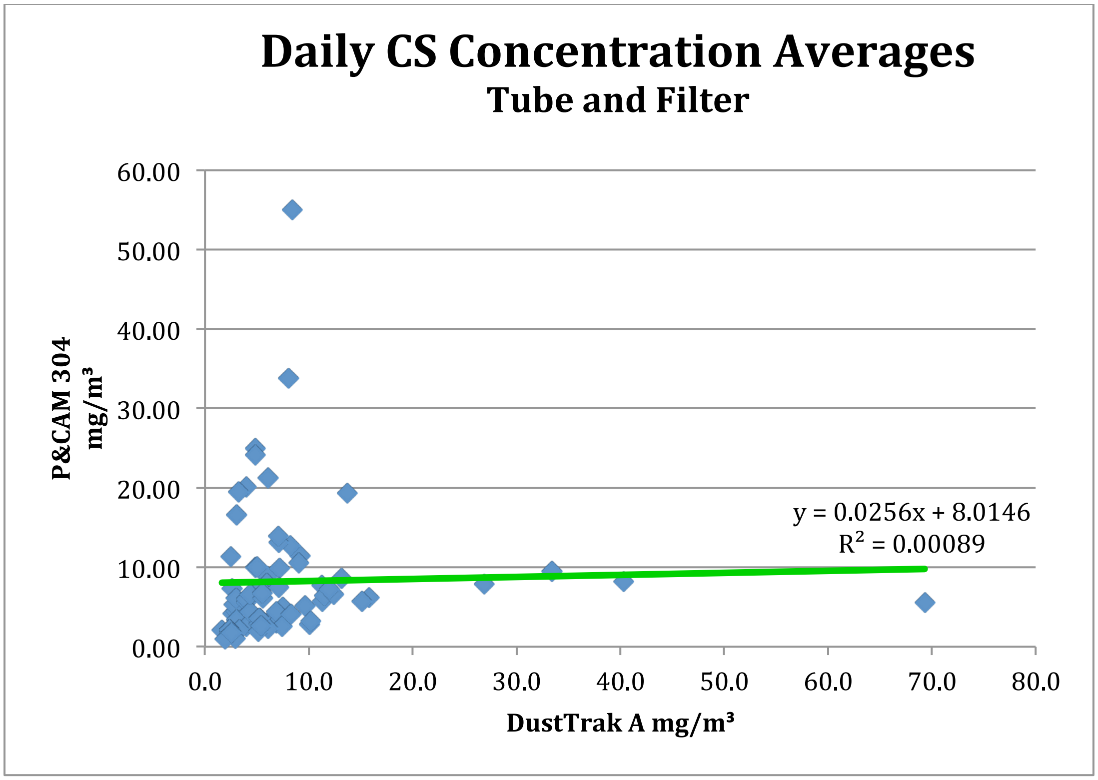
For the comparison study, there were 74 samples taken for case 1. The outlier formula, which is $X > Q3 + 1.5(IQR)$ and $X < Q1 - 1.5\,(IQR)$, was applied to the recorded values from the DustTrak and P&CAM 304 (tube and filter) to determine if outliers existed. The data from the DustTrak and P&CAM 304 (filter and tube) were ordered, the first quartile (Q1), the third quartile (Q3), and the interquartile range (IQR) were all found in order to apply the outlier formula. It was discovered that outliers were present for case 1. CS concentrations above 16 mg/m^3 or below – 4.29 mg/m^3 for the DustTrak were outliers, and CS concentrations for the P&CAM 304 (filter and tube) above 19.04 mg/m^3 or below – 6.08 mg/m^3 were outliers. The outliers for the DustTrak and P&CAM 304 (tube and filter) did not fall on the same sampling day for case 1. DustTrak A's outliers (69.3 mg/m^3, 40.3 mg/m^3, 26.9 mg/m^3, 33.4 mg/m^3), however, did fall on the same day, 24 August 2012, and were associated with the unscheduled sweeping of the inside of the chamber. The P&CAM 304 (tube and filter) had outliers fall on two separate days, on 20 August (19.3 mg/m^3, 33.8 mg/m^3, 55.04 mg/m^3, 21.24 mg/m^3) and 22 August (20.11 mg/m^3, 24.98 mg/m^3, 24.13 mg/m^3, 19.52 mg/m^3).

MS Excel 2010 was used to calculate the paired t-test, and a p-value of 0.952 was calculated for DustTrak and P&CAM 304 (tube and filter) with the outliers included. The research hypothesis is that the DustTrak and the OSHA modified P&CAM 304 methods for sampling CS are comparable. The p-value of 0.952 was larger than the set significance level of 0.05 and indicated that the hypothesis that the two sampling methods for CS are comparable cannot be rejected. When the outliers were removed and the paired t-test was then calculated for case 1, a p-value of 0.56 resulted. This p-value is still larger than the set significance and it remains that the hypothesis cannot be rejected.

Similar results were produced with the paired t-test calculated for the DustTrak and P&CAM 304 (tube and filter) when the values were put on the Log10 scale. A p-value of 0.93 resulted, and when the outliers were removed from the Log10 values the p-value was 0.27. These p-values, 0.93 and 0.27, are still larger than 0.05 and the hypothesis continued to not be rejected.

The correlation coefficient (r) for daily CS concentration averages for DustTrak A and P&CAM 304 (tube and filter) was 0.030 and 0.318 on the Log10 scale. The correlation coefficient for case 1 was 0.25 and 0.42 on the Log10 scale when outliers were removed. All of the calculated correlation coefficients indicated that a very small positive correlation existed between the two methods.

Figure 11 is a graph of the daily CS concentrations averages for DustTrak A and P&CAM 304 (tube and filter) with regression line and is for all sampling days. The very small positive correlation (r = 0.03) can be seen in this graph. As the daily CS concentration average for DustTrak A increased, there was a very small increase in daily CS concentration average from the P&CAM 304 (tube and filter) sampling method. The 95% confidence interval for the slope of the regression line is provided for Figure 1 and is – 0.177 and 0.228. This 95% confidence interval (-0.177, 0.228) contains zero and therefore the research hypothesis that the two sampling methods are comparable cannot be rejected.

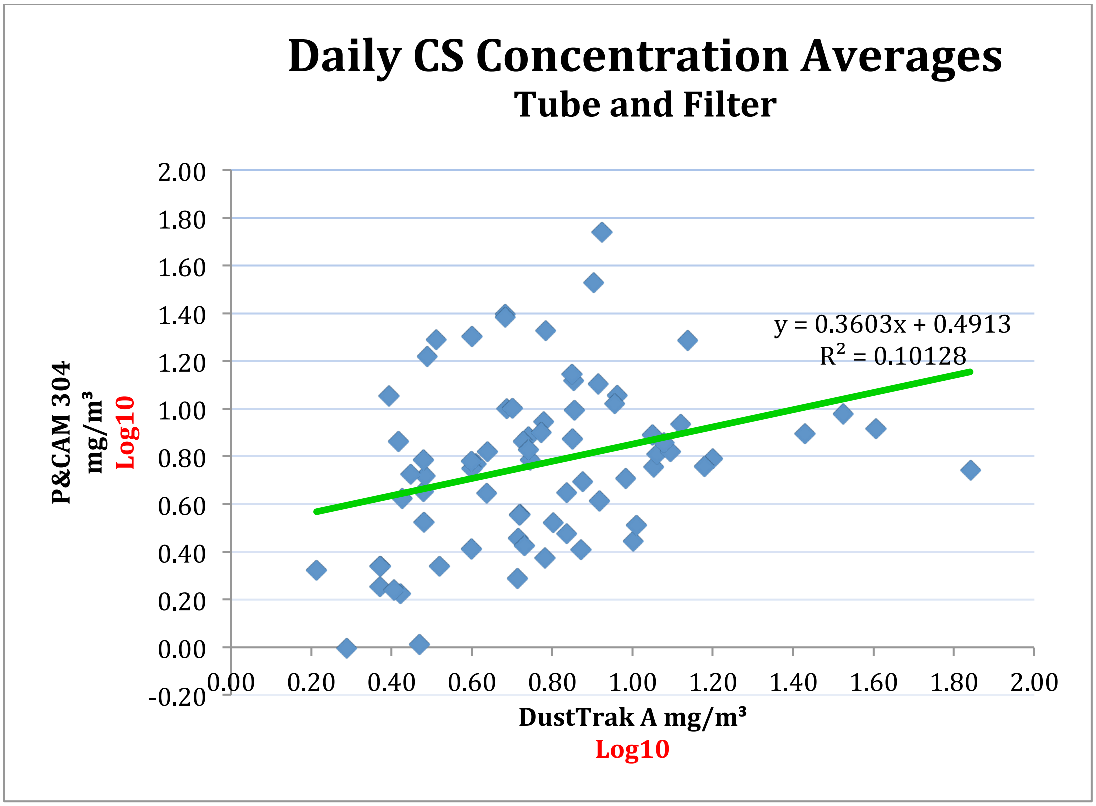


r = 0.03

Regression (R^2)	Slope	Y-intercept	95% Confidence Interval For slope of the regression line	
0.0009	0.0256	8.0146	- 0.177	0.2283

Figure 11. Daily CS Concentration Averages for DustTrak A and P&CAM 304 (tube and filter) with Regression Line

Figure 12 also graphs daily CS concentration averages from DustTrak A and P&CAM 304 (tube and filter) for all sampling days but on the Log10 scale. The correlation coefficient (r = 0.318) is provided, and the 0.318 correlation between the two sampling methods is more visible in Figure 12 than Figure 11. The 95% confidence interval for this regression line is 0.1074 and 0.6137, which does not contain zero and the research hypothesis that the two sampling methods are comparable could be rejected. A graphical representation of the 95% confidence interval for Figure 12 can be found in Appendix B.



r = 0.318

Regression (R^2)	Slope	Y-intercept	95% Confidence Interval For slope of the regression line	
0.1013	0.3603	0.4913	0.1074	0.6137

Figure 12. Log10 Daily CS Concentration Averages for DustTrak A and P&CAM 304 (tube/filter) with Regression Line

It was necessary to find the degree of agreement between the DustTrak and P&CAM 304 for the comparison study, and the Bland-Altman Plot was used for this. The Bland-Altman Plot is used to compare two measurement methods where the differences between the two methods (DustTrak and P&CAM 304) are plotted against the averages of the two methods (11) . The Bland-Altman Plot was selected as a statistical tool because using the correlation coefficient (r) between the two measurement methods as an indicator of agreement would be incorrect (11). A high correlation does not mean

that the two methods agree. Correlation measures the strength of a relation between two variables, not the agreement between them.

Table 3 presents the daily CS concentration averages for DustTrak A and P&CAM 304 (tube and filter) from 29 August 2012 and includes the Bland-Altman statistics. The values for all sampling days can be found in Appendix C. The Bland-Altman statistics were determined by calculating the mean of the daily CS concentration averages from DustTrak A and P&CAM 304 (tube and filter), then calculating the difference between the daily CS concentration averages from the two sampling methods.

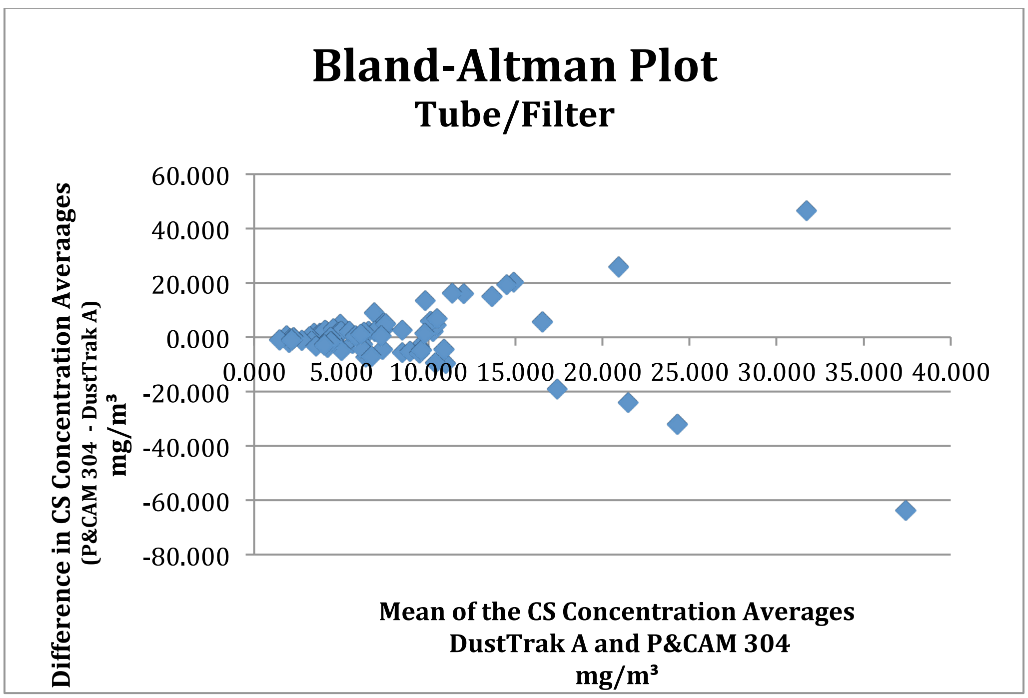
Table 3. Daily CS Concentration Averages for DustTrak A and P&CAM 304 (tube/filter) with Bland-Altman Statistics

Sample	**DustTrak A Daily CS Avg mg/m³**	**P&CAM 304 Daily CS Avg (tube/filter) mg/m³**	Bland-Altman Statistics **Mean of the CS Averages from DustTrak A and P&CAM 304(tube/filter) mg/m³**	Bland-Altman Statistics **Difference in CS Averages for P&CAM 304 (tube/filter) and DustTrak A mg/m³**
29/08/2012 Plt 1	3.03	3.34	3.18	0.31
29/08/2012 Plt 2	3.97	2.58	3.27	-1.40
29/08/2012 Plt 3	3.31	2.18	2.75	-1.12
29/08/2012 Plt 4	2.64	1.67	2.16	-0.97
29/08/2012 NCO	2.95	1.03	1.99	-1.92

Figure 13 is the Bland Altman Plot, which graphs the mean CS concentration average from DustTrak A and P&CAM 304 (tube and filter) (x-axis) against the difference in CS concentration averages between DustTrak A and P&CAM 304 (y-axis). Listed with Figure 3 is P&CAM 304 (tube and filter) CS concentration average for all samples taken, 8.22 mg/m³, and DustTrak A's CS concentration average for all samples, 8.10 mg/m³. These CS concentration averages, 8.22 mg/m³ and 8.10 mg/m³, were for all samples taken (all platoons), and included the CBRNE NCO personal sampler results. The difference between these two averages (mean difference, $\bar{d}$) is also listed and is

0.12mg/m³, and the standard deviation (s) for the differences between the two sampling methods is 6.6 mg/m³. The limits of agreement, are also provided with Figure 13, and are – 13.1 mg/m³ and + 13.3 mg/m³. Limits of agreement were found by taking the mean difference ($\bar{d}$) and adding two standard deviations to it, and then subtracting two standard deviations from it ($\bar{d} \pm 2s$). A level of agreement does exist between DustTrak A and P&CAM 304 and is representative in Figure 13.

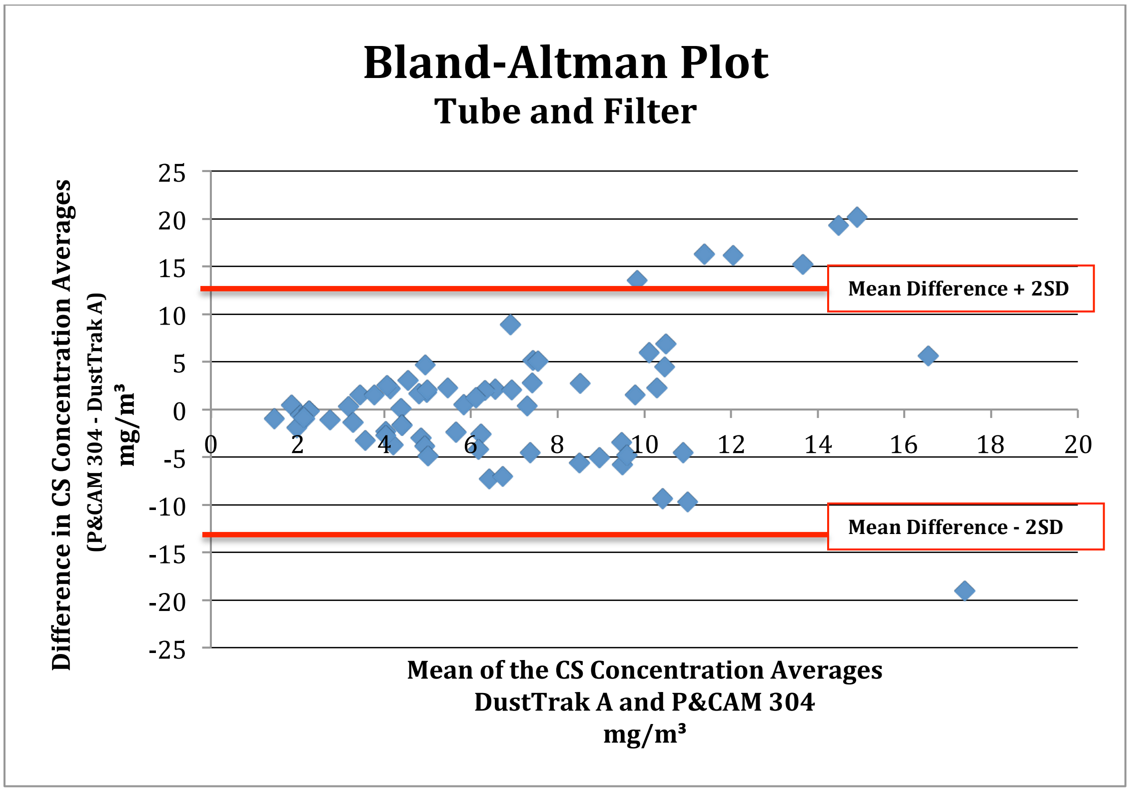
As the mean of the two sampling methods increased, the difference between the two methods also increased. Much of the data points cluster at 10 mg/m³ and lower, indicating that a lower CS concentration mean leads to a smaller difference between the two sampling methods.



P&CAM 304 CS Avg (tube/filter) All Samples	DustTrak A CS Avg All Samples	Mean Differences $\bar{d}$	Standard Deviation of the differences between sampling methods s	Limits of Agreement $\bar{d} \pm 2s$	
8.22 mg/m³	8.10 mg/m³	0.12 mg/m³	6.6 mg/m³	- 13.1 mg/m³	+ 13.3 mg/m³

Figure 13. Bland-Altman Plot for DustTrak A and P&CAM 304 (tube and filter)

Figure 14 is another representation of the Bland-Altman Plot and focuses more on the limits of agreement between DustTrak A and P&CAM 304 (tube and filter). The limits of agreement are – 13.1 mg/m³ and + 13.3 mg/m³, and it is more visible in Figure 14 that most of the data points fall within the range of the limits of agreement. However, this agreement level is weak as a discrepancy of up to 13 mg/m³ can exist between the two sampling methods. It is more evident in Figure 14 that at a mean CS concentration of 10 mg/m³ and lower, a smaller difference between the two sampling methods existed.



P&CAM 304 CS Avg (tube/filter) All Samples	DustTrak A CS Avg All Samples	Mean Differences $\bar{d}$	Standard Deviation of the differences between sampling methods s	Limits of Agreement $\bar{d} \pm 2s$	
8.22 mg/m³	8.10 mg/m³	0.12 mg/m³	6.6 mg/m³	- 13.1 mg/m³	+ 13.3 mg/m³

Figure 14. Bland-Altman Plot for DustTrak A and P&CAM 304 (tube/filter) with Limits of Agreements

The results produced for case 2 of the comparison study, DustTrak to P&CAM 304 (filter only) are presented in a similar fashion as case 1's results. The same statistical analysis were conducted, the paired t-test, correlation coefficients, Bland-Altman Plot, when looking at the P&CAM (filter) information with the DustTrak.

Table 4 represents information from one day of sampling, 29 August 2012, with DustTrak A and P&CAM 304 (filter), and information on the daily CS concentration averages for all sampling days can be found in Appendix D. Displayed in Table 4 are the daily CS concentrations averages for DustTrak A and values for the fiber filter of P&CAM 304. DustTrak A and P&CAM 304 (filter) values were also given in Log10 due to the presence of outliers.

Table 4. Daily CS Concentration Averages with DustTrak A and P&CAM 304 (filter)

Sample	**DustTrak A Daily CS Avg mg/m³**	**P&CAM 304 Daily CS Avg (filter) mg/m³**	**DustTrak A Daily CS Avg mg/m³ Log10**	**P&CAM 304 Daily CS Avg (filter) mg/m³ Log10**
29/08/2012 Plt 1	3.03	0.002	0.48	-2.78
29/08/2012 Plt 2	3.97	0.001	0.60	- 2.94
29/08/2012 Plt 3	3.31	0.001	0.52	- 2.94
29/08/2012 Plt 4	2.64	0.002	0.42	- 2.64
29/08/2012 NCO	2.95	0.045	0.47	- 1.34

Outliers in case 2 were determined in the same manner as in case 1, where the outlier formula was applied. The DustTrak outliers did not change, and outliers existed if CS concentrations were above 16 mg/m³ or below – 4.09 mg/m³, and all occurred on 24 August 2012. For P&CAM 304 (filter) outliers were present if CS concentrations were above 7.27 mg/m³, or below – 4 mg/m³. P&CAM 304 (filter) had outliers on the same days as P&CAM 304 (tube and filter), 20 and 22 August 2012. P&CAM 304 (filter) outlier values for 20 August were 12.59 mg/m³, 26.66 mg/m³, 48.25 mg/m³, 20.74

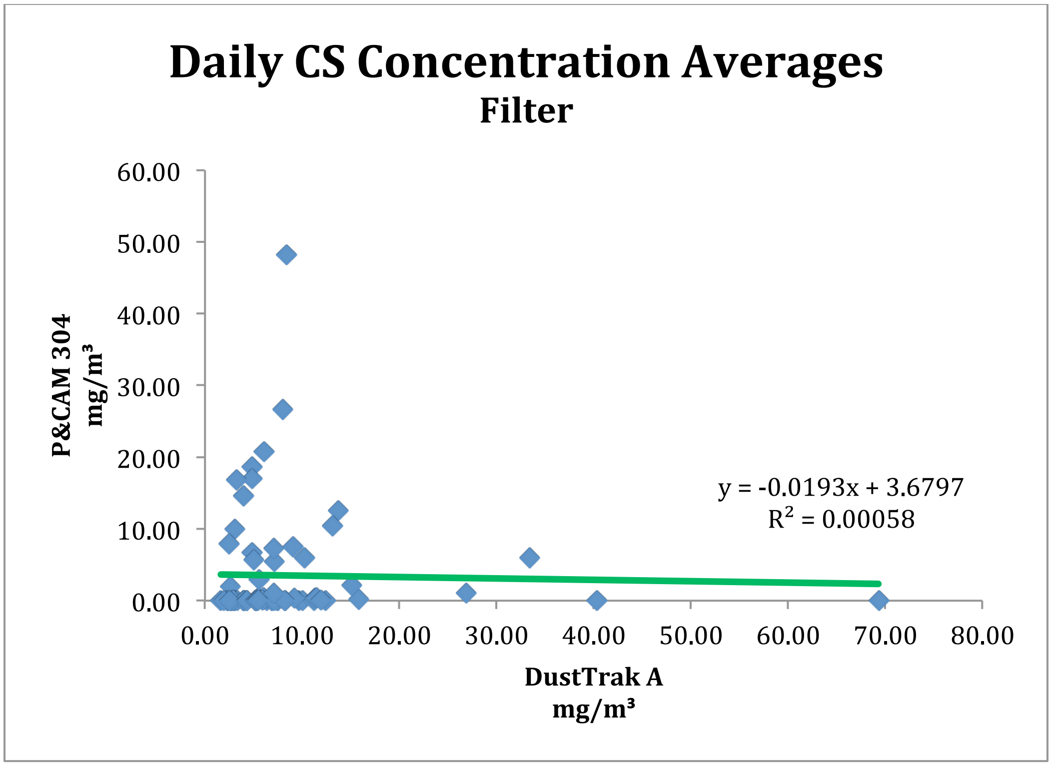
mg/m³, and 22 August had outlier values of 14.66 mg/m³, 18.66 mg/m³, 17.03 mg/m³, 9.99 mg/m³, 16.86 mg/m³. P&CAM 304 (filter) had additional outliers on 27 August (7.97 mg/m³), 12 September (10.41 mg/m³, 7.27 mg/m³) and 14 September (7.47 mg/m³).

MS Excel 2010 was used to calculate the p-value from the paired t-test, and the reported p-value is 0.002 and < 0.001 for the Log10 values. Both of these p-values are lower than the set significance level of 0.05, resulting in the rejection of the hypothesis that the DustTrak and P&CAM 304 (filter) are comparable. When the paired t-test was conducted with the outliers removed, a p-value of zero resulted in both instances when the data was not on the Log scale and when it was put in Log10.

The correlation coefficient (r) for daily CS concentration averages for DustTrak A and P&CAM 304 (filter) is -0.024, and when the outliers are removed the same correlation coefficient results. These low negative correlation coefficients indicated that as the daily CS concentration average for DustTrak A increased, there was a small decrease in the daily CS concentration average for P&CAM 304 (filter). The correlation coefficient is 0.254 for the Log10 values of DustTrak A and P&CAM 304 (filter), which gives a very small positive correlation between DustTrak A and P&CAM 304 (filter). The same findings were produced when the correlation coefficient was calculated for the Log10 values with the outliers removed. In this instance, the correlation coefficient was again a very small positive value of 0.21.

Figure 15 is a graph of the daily CS concentration averages for DustTrak A and P&CAM 304 (filter) with regression line and is representative for all sampling days. The very small negative correlation (r = - 0.002) is visible in Figure 15, as the daily CS concentration average for DustTrak A increased, there was a very small decrease in daily

CS concentration average from the P&CAM 304 (filter) sampling method. The 95% confidence interval for the slope of the regression line is provided for Figure 15 and is – 0.209 and 0.228. This 95% confidence interval (-0.209, 0.228) contains zero and therefore the hypothesis that the two sampling methods are comparable cannot be rejected.



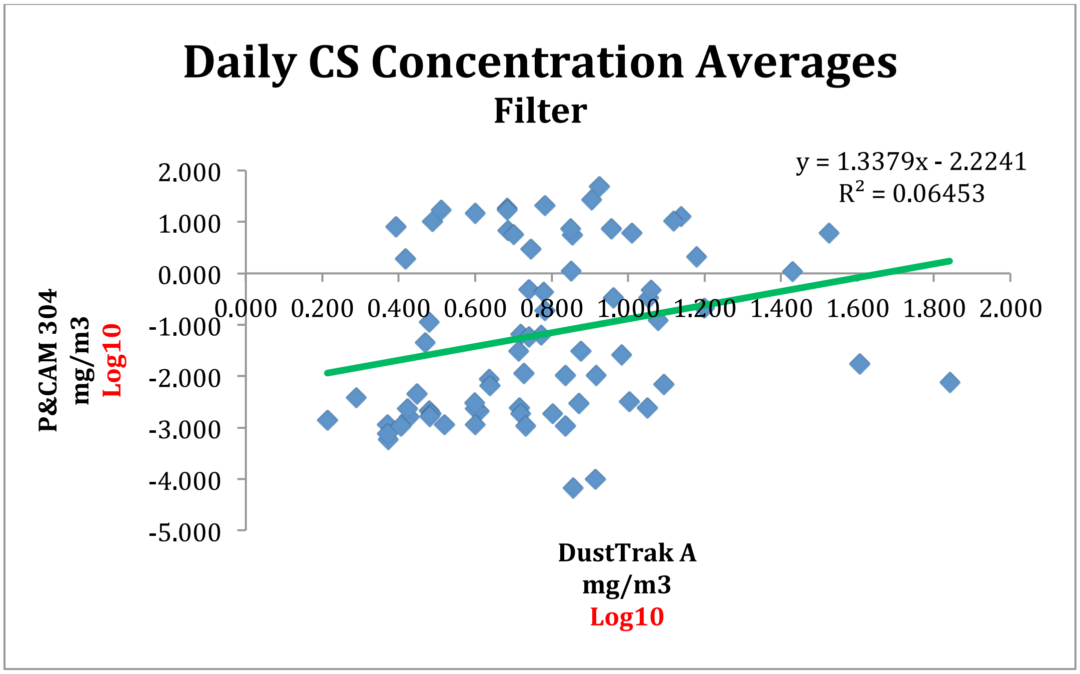
r = - 0.002

Regression (R^2)	Slope	Y-intercept	95% Confidence Interval For slope of the regression line	
0.0006	- 0.019	3.68	- 0.209	0.2283

Figure 15. Daily CS Concentration Averages for DustTrak A and P&CAM 304 (filter) with Regression Line

Figure 16 also graphs daily CS concentration averages from DustTrak A and P&CAM 304 (filter) but on the Log10 scale. The correlation coefficient (r = 0.254) can be seen in this graph, however, even though this is a positive correlation, it is a very small

positive correlation and does not translate to a strong association between the two sampling methods. The 95% confidence interval is given for the slope of the regression line, and is (0.138, 2.54). This confidence interval does not contain zero, the hypothesis can be rejected, and the two sampling methods are not comparable. A graph of the 95% confidence interval for Figure 6 can be found in Appendix E.



r = 0.254

Regression (R^2)	Slope	Y-intercept	95% Confidence Interval For slope of the regression line	
0.064	1.33	-2.22	0.138	2.54

Figure 16. Log10 Daily CS Concentration Averages for DustTrak A and P&CAM 304 (filter) with Regression Line

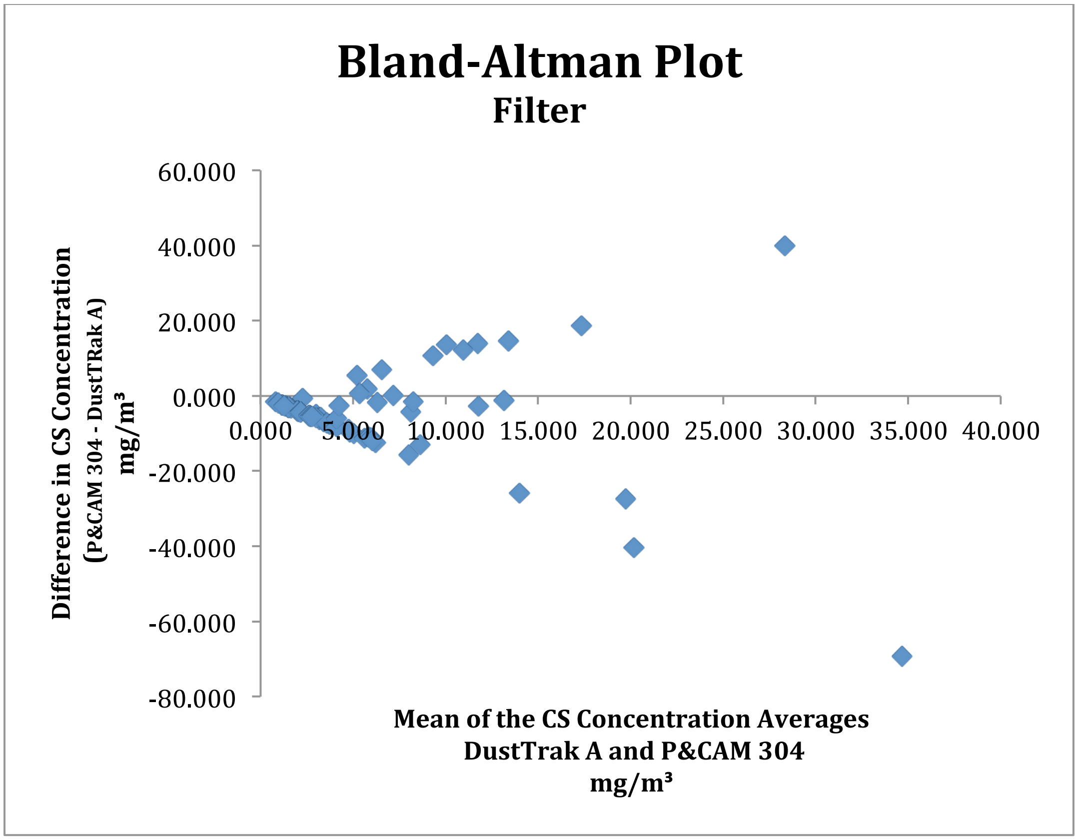
Table 5 contains daily CS concentration averages for DustTrak A and P&CAM 304 (filter) for 29 August 2012, and includes the Bland-Altman statistics. The Bland-Altman statistics were found by getting the mean of the daily CS concentration averages from DustTrak A and P&CAM 304 (filter) and determining the difference between the

daily CS concentration averages from the two sampling methods. Table 5 values for all sampling days can be found in Appendix F.

Table 5. Daily CS Concentration Averages for DustTrak A and P&CAM 304 (filter) With Bland-Altman Statistics

Sample	**DustTrak A Daily CS Avg mg/m³**	**P&CAM 304 Daily CS Avg (filter) mg/m³**	Bland-Altman Statistics **Mean of the CS Averages from DustTrak A and P&CAM 304(filter) mg/m³**	Bland-Altman Statistics **Difference in CS Averages for P&CAM 304 (filter) and DustTrak A mg/m³**
29/08/2012 Plt 1	3.028	0.002	1.515	-3.026
29/08/2012 Plt 2	3.973	0.001	1.987	- 3.972
29/08/2012 Plt 3	3.307	0.001	1.654	- 3.306
29/08/2012 Plt 4	2.645	0.002	1.324	- 2.642
29/08/2012 NCO	2.949	0.0045	1.497	- 2.904

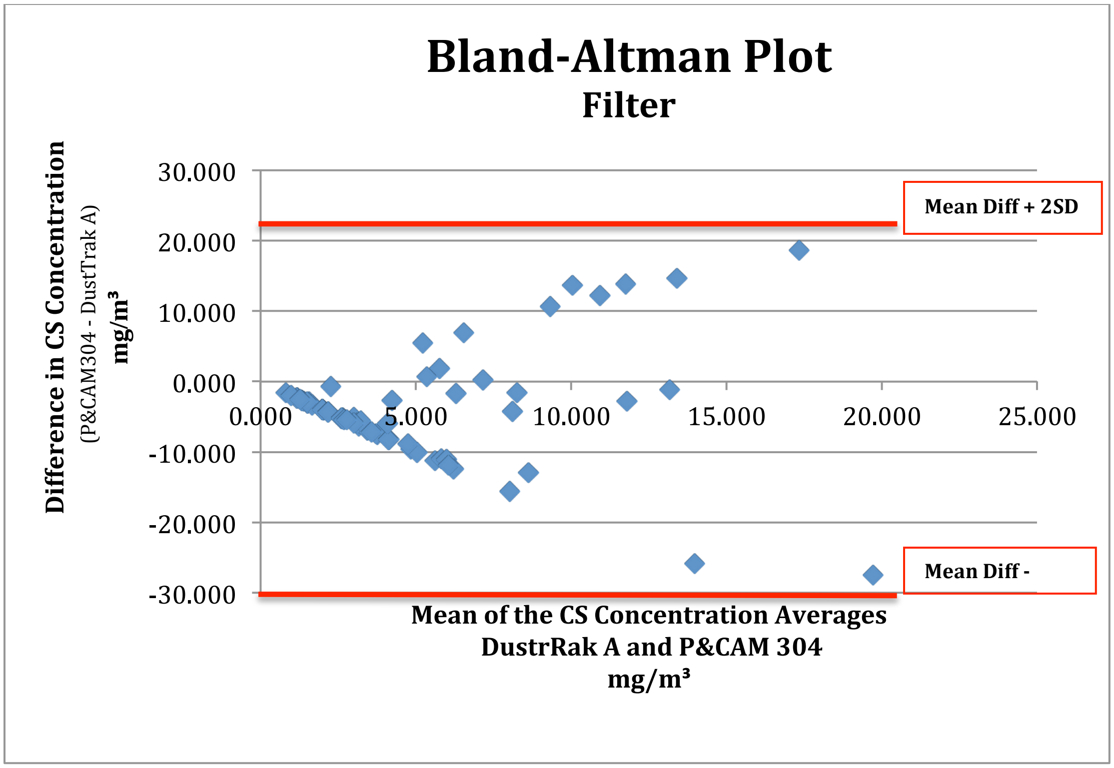
The Bland Altman Plot was also constructed for the comparison between DustTrak A and P&CAM 304 (filter). Figure 17 graphs the mean CS concentration average from DustTrak A and P&CAM 304 (filter) (x-axis) against the difference in CS concentration averages between DustTrak A and P&CAM 304 (filter) (y-axis). Listed with Figure 17 is P&CAM 304 (filter) CS concentration average for all samples taken, 3.52 mg/m³, and DustTrak A's CS concentration average for all samples, 8.10 mg/m³. The mean difference (¯d) is – 4.61mg/m³, and the standard deviation (s) for the differences between the two sampling methods is 12.56 mg/m³. The limits of agreement, are – 29.7 mg/m³ and 20.5 mg/m³. From Figure 17, it can be seen that a level of agreement does exist between DustTrak A and P&CAM 304 (filter). As the mean of the two sampling methods increased, the difference between the two methods also increased. Much of the data points cluster at 9 mg/m³ and lower, indicating that a lower CS concentration mean leads to a smaller difference between the two sampling methods.



P&CAM 304 CS Avg (filter) All Samples	DustTrak A CS Avg All Samples	Mean Differences $\bar{d}$	Standard Deviation of the differences between the two sampling methods s	Limits of Agreement $\bar{d} \pm 2s$	
3.52 mg/m^3	8.13 mg/m^3	- 4.61 mg/m^3	12.56 mg/m^3	- 29.7 mg/m^3	20.5 mg/m^3

Figure 17. Bland-Altman Plot for DustTrak A and P&CAM 304 (filter)

In order to better portray the agreement level between DustTrak A and P&CAM 304 (filter), Figure 18 was constructed focusing on the limits of agreement. The limits of agreement are – 29.7 mg/m^3 and + 20.5 mg/m^3, this agreement level is weak as a discrepancy of up to 30 mg/m^3 can exist between the two sampling methods. It is more evident in Figure 18 that at a mean CS concentration of 9 mg/m^3 and lower, a smaller difference between the two sampling methods exists.



P&CAM 304 CS Avg (filter) All Samples	DustTrak A CS Avg All Samples	Mean Differences $\bar{d}$	Standard Deviation of the differences between the two sampling methods s	Limits of Agreement $\bar{d} \pm 2s$	
3.52 mg/m^3	8.13 mg/m^3	- 4.61 mg/m^3	12.56 mg/m^3	- 29.7 mg/m^3	20.5 mg/m^3

Figure 18. Bland-Altman Plot for DustTrak A and P&CAM 304 (filter)

The Bland-Altman statistics were constructed without the outliers for both case 1 and case 2 of the comparison study. For case 1, DustTrak to P&CAM 304 (tube and filter), the limits of agreement were + 8.12 mg/m^3 and – 8.76 mg/m^3. For case 2, when just the P&CAM 304's filter was compared to the DustTrak, the limits of agreement were + 2.47 mg/m^3 and – 12.97 mg/m^3.

Figures 19 – 21 are graphical representations of the Kruskal-Wallis tests for DustTrak A, P&CAM 304, and DustTrak B, respectively. The Kruskal-Wallis test analyzed CS concentration accumulation inside the mask confidence chamber as each

platoon completed their training. A company completed mask confidence chamber training in a sequential order; platoon 1 was always first to enter the chamber, followed by platoon 2, then platoon 3, with platoon 4 being last to enter the chamber and complete training. In Figures 19 – 21 the samples on the x-axis represent groups of platoons. Sample 1 represents all of the platoons, from all companies, that were first to enter the chamber and complete their mask confidence chamber training (platoon 1). Sample 2 represents all of platoons that were second to complete mask confidence chamber training (platoon 2), sample 3 represents every company's platoon 3, and sample 4 groups together all of the platoons that were last to complete training (platoon 4). There were seventeen platoons counted for each sample (platoon groups).

Figures 19 – 21 were produced from IBM SPSS statistics, and provided with each of these graphs are the null hypothesis and significance level of the Kruskal-Wallis test. The null hypothesis for each sampling method, DustTrak A, P&CAM 304, and DustTrak B, is that the distribution of CS concentration will be the same across each categories of sample (groups of platoon), meaning that there will not be an accumulation of CS concentration throughout the duration of a training day. In Figures 19 – 21, each sample's information is presented in a box and whisker plot where there dark line represents the median of the sample.

The mean CS concentration for DustTrak A was 5.78 mg/m^3 for sample 1 (Figure 19), and this value was found by averaging all seventeen of platoon 1's CS concentration averages. As Figure 19 demonstrates, there was an outlier in sample 1 with a CS concentration average of 13.8 mg/m^3, the standard deviation was 2.89 mg/m^3, and the minimum and maximum concentration averages being 2.1 mg/m^3 and 10 mg/m^3. The

mean CS concentration for sample 2 was 7.71 mg/m^3 with a standard deviation of 3.49 mg/m^3, and the minimum and maximum CS concentration averages being 2.8 mg/m^3 and 15mg/m^3. Sample 3 had a mean CS concentration average of 8.58 mg/m^3, a standard deviation of 4.32 mg/m^3, a minimum concentration average of 2.8 mg/m^3 and a maximum of 18.2 mg/m^3. Sample 4, which grouped together all of the platoons, from the seventeen companies, that were last to complete mask confidence chamber training had a mean CS concentration average of 8.21 mg/m^3, and a standard deviation of 5.20. There was an outlier in sample 4 with a value of 23.7 mg/m^3, with the minimum and maximum CS concentration averages are 2.8 mg/m^3 and 13.3 mg/m^3. The medians for DustTrak A (dark lines in box whisker plot) are 5.4 mg/m^3 for sample 1, 7.3 mg/m^3 for sample 2, 7.5 $mg/m^3$for sample 3, and 7.2 mg/m^3 for sample 4.

Figure 20 shows the results of the Kruskal-Wallis Test for P&CAM 304. The mean CS concentration was 6.25 mg/m^3 for sample 1. As Figure 20 demonstrates, there was an outlier in sample 1 with a CS concentration average of 19.6 mg/m^3, the standard deviation was 4.91 mg/m^3, and the minimum and maximum concentration averages being 1.74 mg/m^3 and 14.9 mg/m^3. The mean CS concentration for sample 2 was 8.30 mg/m^3, and had an outlier of 34 mg/m^3. The standard deviation for sample 2 was 7.62 mg/m^3, and the minimum and maximum CS concentration averages being 2.18 mg/m^3 and 13.1 mg/m^3. Sample 3 had a mean CS concentration average of 10.46 mg/m^3, a standard deviation of 13.0 mg/m^3, a minimum concentration average of 1.79 mg/m^3 and a maximum of 24 mg/m^3. Sample 3 had a very large outlier with a CS concentration of 55.2 mg/m^3. Sample 4, had a mean CS concentration average of 5.60 mg/m^3, and a standard deviation of 3.05 mg/m^3. There is an outlier in sample 4 with a value of 12.5

mg/m^3, but the minimum and maximum CS concentration averages are 1.67 mg/m^3 and 9.89 mg/m^3. The medians for sample 1 through 4 are 4.24 mg/m^3, 5.70 mg/m^3, 5.74 mg/m^3 and 5.34, respectively.

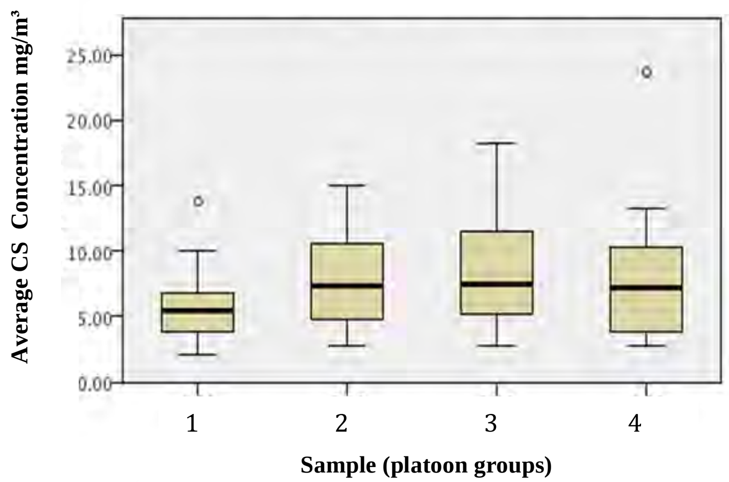
For DustTrak A and P&CAM 304, the hypothesis that the distribution of CS concentration would stay the same across the different categories of sample (platoon group) was retained. The set significance level was 0.05, and for DustTrak A the significance reported after the Kruskal-Wallis Test was .185, and for P&CAM 304 it was .574. Both of these values, .185 and .574, are greater than the significance level of 0.05 and the hypothesis is not rejected. CS concentration does not accumulate over the duration of a training day, and regardless of what sequence a recruit completes mask confidence chamber training (in the first platoon, or the last platoon), there is not a statistically significant increase in CS concentration that they would be exposed to.

Figure 21A illustrations the results from the Kruskal-Wallis Test for DustTrak B, where no outliers were present. The mean CS concentration was 4.32 mg/m^3 for sample 1, the median was 4.4 mg/m^3, the standard deviation was 1.54 mg/m^3, and the minimum and maximum concentration averages being 1.74 mg/m^3 and 14.9 mg/m^3. The mean CS concentration for sample 2 was 6.36 mg/m^3, median of 6.6 mg/m^3, a standard deviation of 2.51 mg/m^3, and the minimum and maximum CS concentration averages being 2.18 mg/m^3 and 13.1 mg/m^3. Sample 3 had a mean CS concentration average of 7.91 mg/m^3, a median of 7.1 mg/m^3, a standard deviation of 3.89 mg/m^3, a minimum concentration average of 1.79 mg/m^3 and a maximum of 24 mg/m^3. A mean CS concentration of 7.82 mg/m^3 was found for sample 4, standard deviation of 4.12 mg/m^3, minimum CS

concentration at 2.2 mg/m^3 and a maximum at 13.4 mg/m^3. The median for sample 4 fell at 7.1 mg/m^3.

For DustTrak B the significance level produced from the Kruskal-Wallis Test was .005, which is less than the set significance of 0.05 and the hypothesis is rejected. The results from the Kruskal-Wallis Test indicated that for DustTrak B, there was an increase in CS concentration as the different platoons advanced through the mask confidence chamber and completed their training. In Figure 21B the pairwise comparison of the different samples (platoon groups) is shown. When compared to each other, platoon 1 always has a lower CS concentration average than platoon 3 and platoon 4. The Kruskal-Wallis Test results for DustTrak B do indicate that recruits in platoon 3 and platoon 4 are exposed to a higher CS concentration level than recruits in platoon 1.

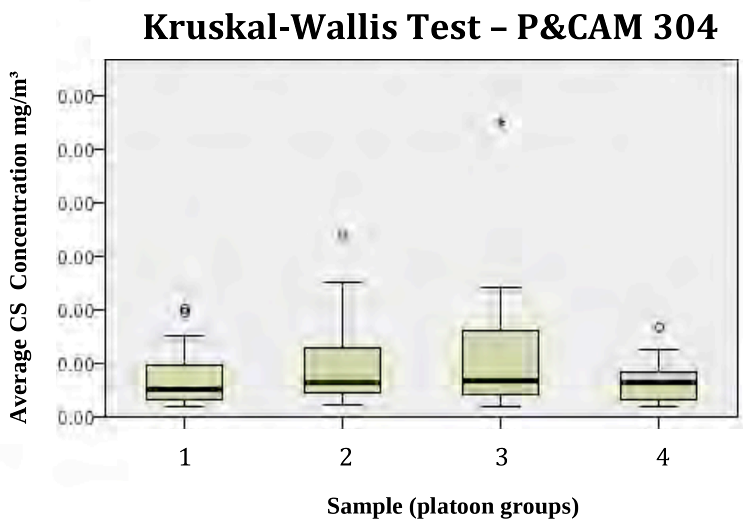
Kruskal-Wallis Test – DustTrak™ A



Kruskal-Wallis Test – DustTrak™ A				
	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CS concentration for DustTrak™ A is the same across categories of sample (platoon groups)	Independent-Samples Kruskal-Wallis Test	.185	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 19. Kruskal-Wallis Test for CS accumulation for DustTrak A across platoon groups

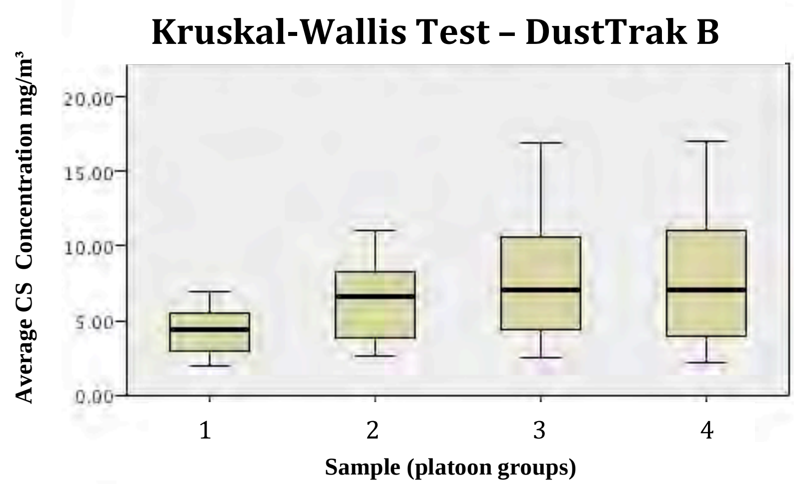


Kruskal-Wallis Test – P&CAM 304

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of CS concentration for P&CAM 04 is the same across categories of sample (platoon groups).	Independent-Samples Kruskal-Wallis Test	.574	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 20. Kruskal-Wallis Test for CS accumulation for P&CAM 304 across platoon groups



Kruskal-Wallis Test – DustTrak™ B				
	Null Hypothesis	**Test**	**Sig.**	**Decision**
1	The distribution of CS concentration for DustTrak™ B is the same across categories of sample (platoon groups)	Independent-Samples Kruskal-Wallis Test	.005	Reject the null hypothesis.
Asymptotic significances are displayed. The significance level is .05.				

Figure 21A. Kruskal-Wallis Test for CS accumulation for DustTrak B across platoon groups

DustTrak B
Pairwise Comparisons of Sample

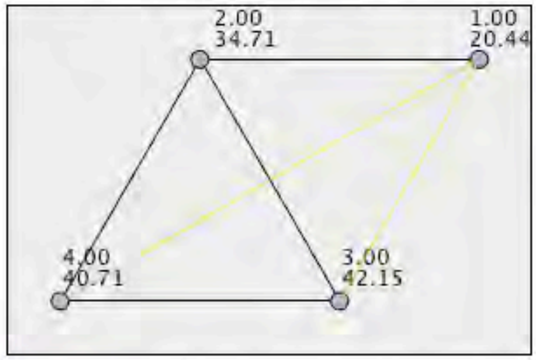


Figure 21B. DustTrak B - Pairwise Comparison of Sample (Platoon Groups) for CS Accumulation

Figures 22-24 are graphs produced by the DustTrak data analysis software, TrakPro. DustTrak A and B take readings of the CS particulate matter levels (mg/m³) every 5 seconds, and continue to do so for the entire duration of mask confidence chamber training.

Figure 22 is an example of the readings recorded by DustTrak A and is from a normal day of mask confidence chamber training, 29 August 2012 (Table 2 - 4 values are for this sampling day). Figure 22 labels the various activities that occur during mask confidence chamber training, when background samples are taken, when the CBRNE NCO enters and exits the chamber, when the chamber is charged with CS and when the different platoons conduct their training.

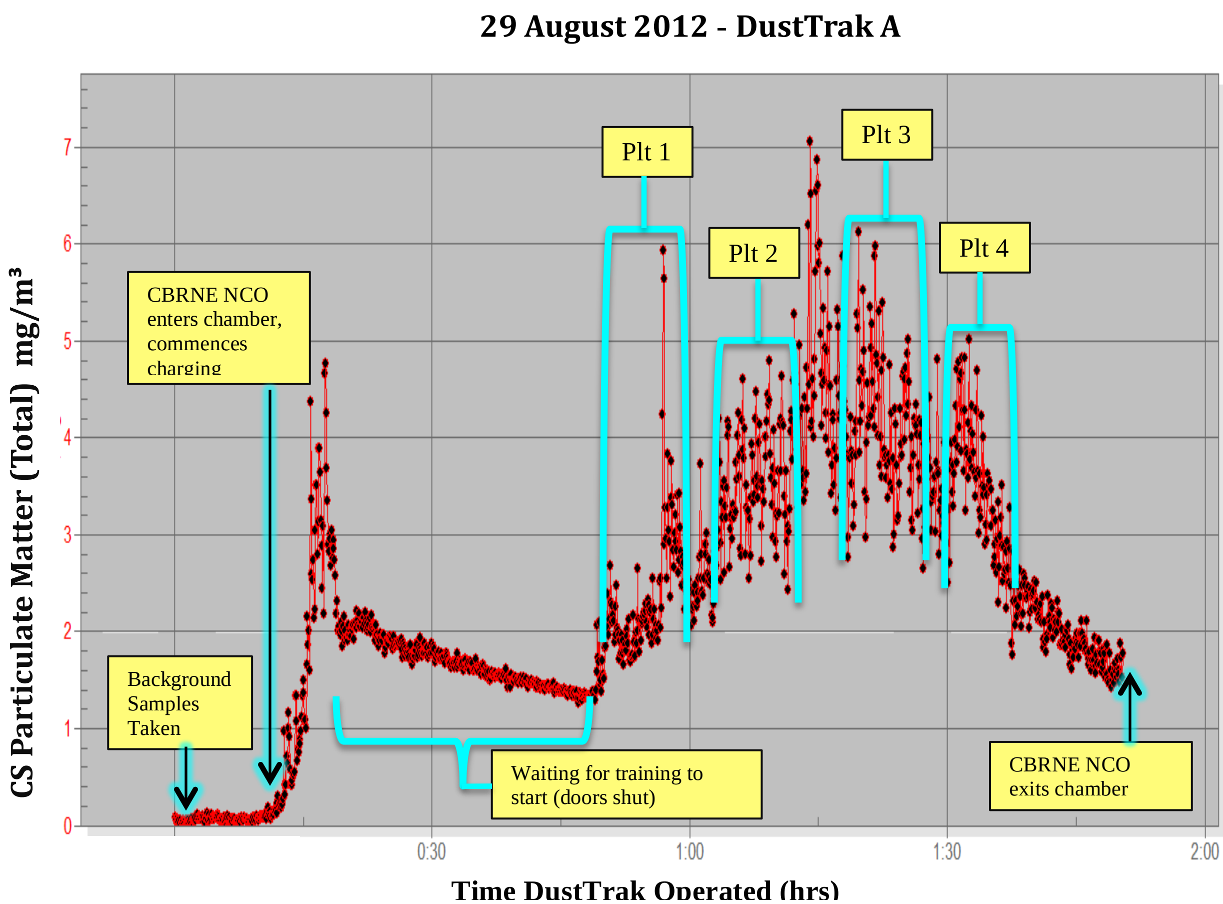


Figure 22. DustTrak on a sampling on a normal day, 29 August 2012

Figure 23 displays a day of sampling during mask confidence chamber training using DustTrak A, 24 August 2012. During this sampling day, the CBRNE NCO swept the inside of the chamber while changing it with CS. Figure 13 labels when background samples were taken, when the CBRNE NCO enters and exits the chamber, and identifies the peak particulate matter reading for DustTrak A.

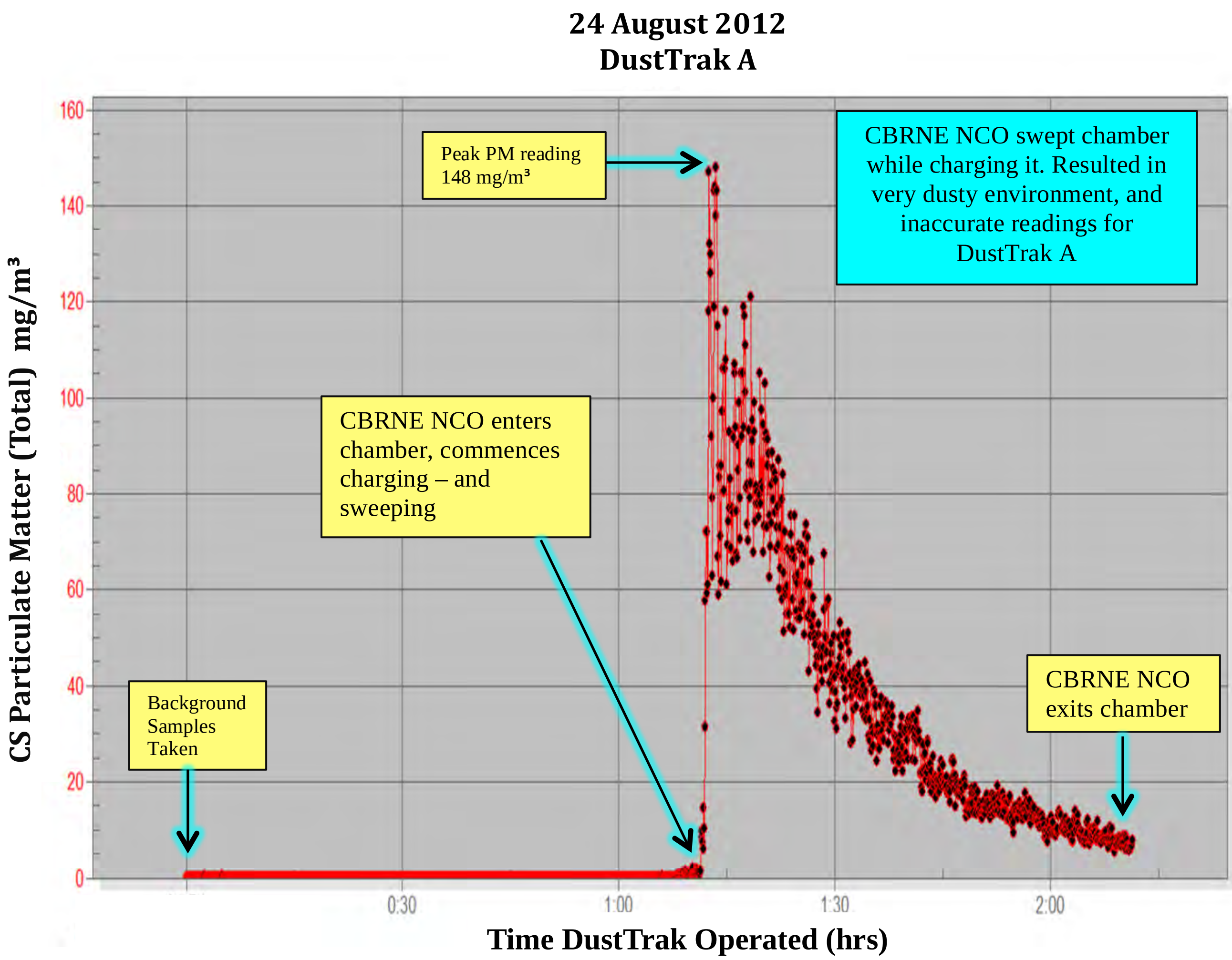


Figure 23A. DustTrak A, sampling when the inside of the chamber was swept

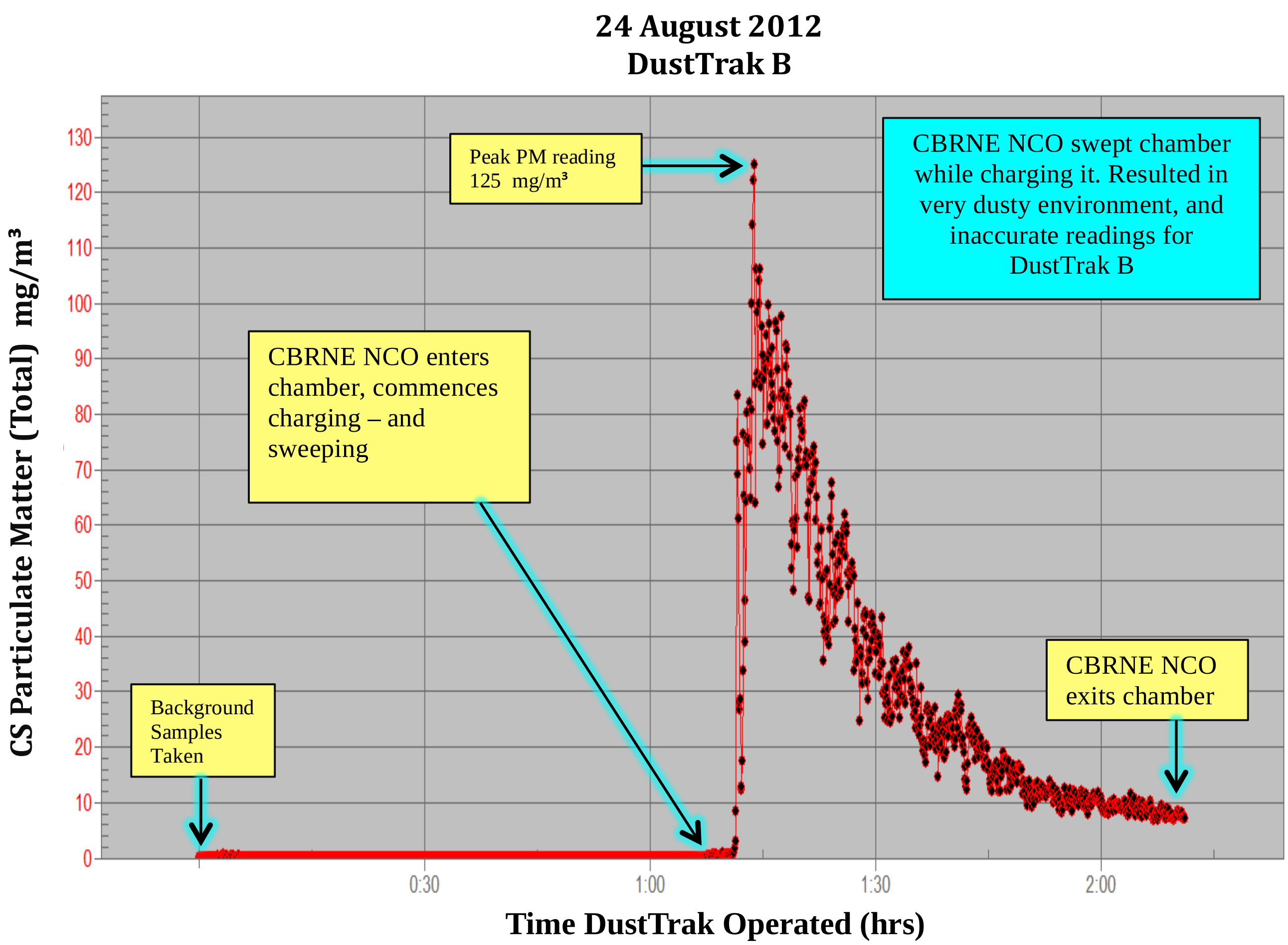


Figure 23B. DustTrak B, sampling when the inside of the chamber was swept

Figure 24 exhibits a day of sampling inside the mask confidence chamber with both DustTrak A and DustTrak B, 21 August 2012. On this day of sampling, DustTrak A became unserviceable, and Figure 24A is the graph of the data logged on that day by DustTrak A. Figure 24B is a graph showing the data logged by DustTrak B on the same day that DustTrak A became unserviceable.

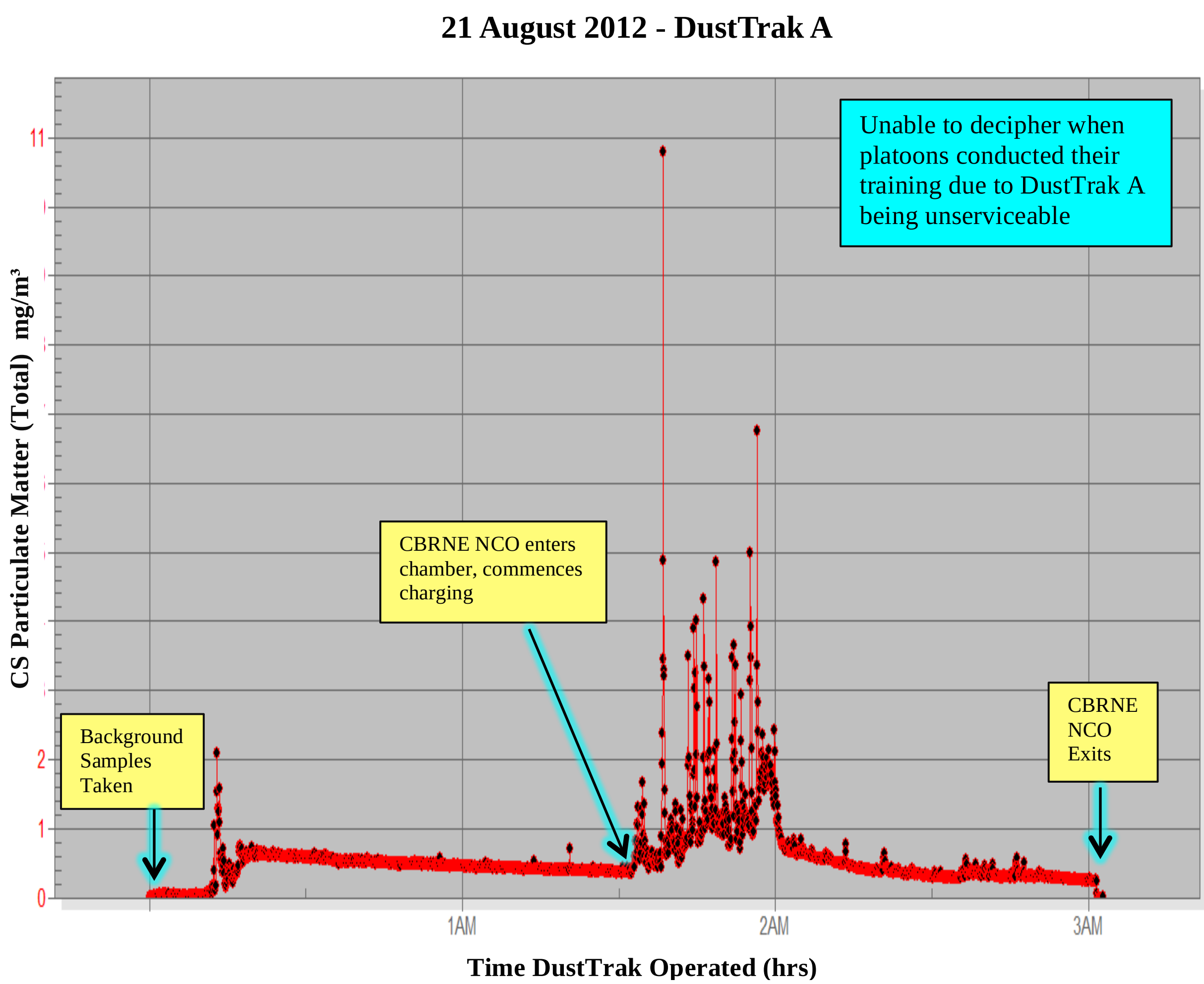


Figure 24A. Sampling when DustTrak A became unserviceable

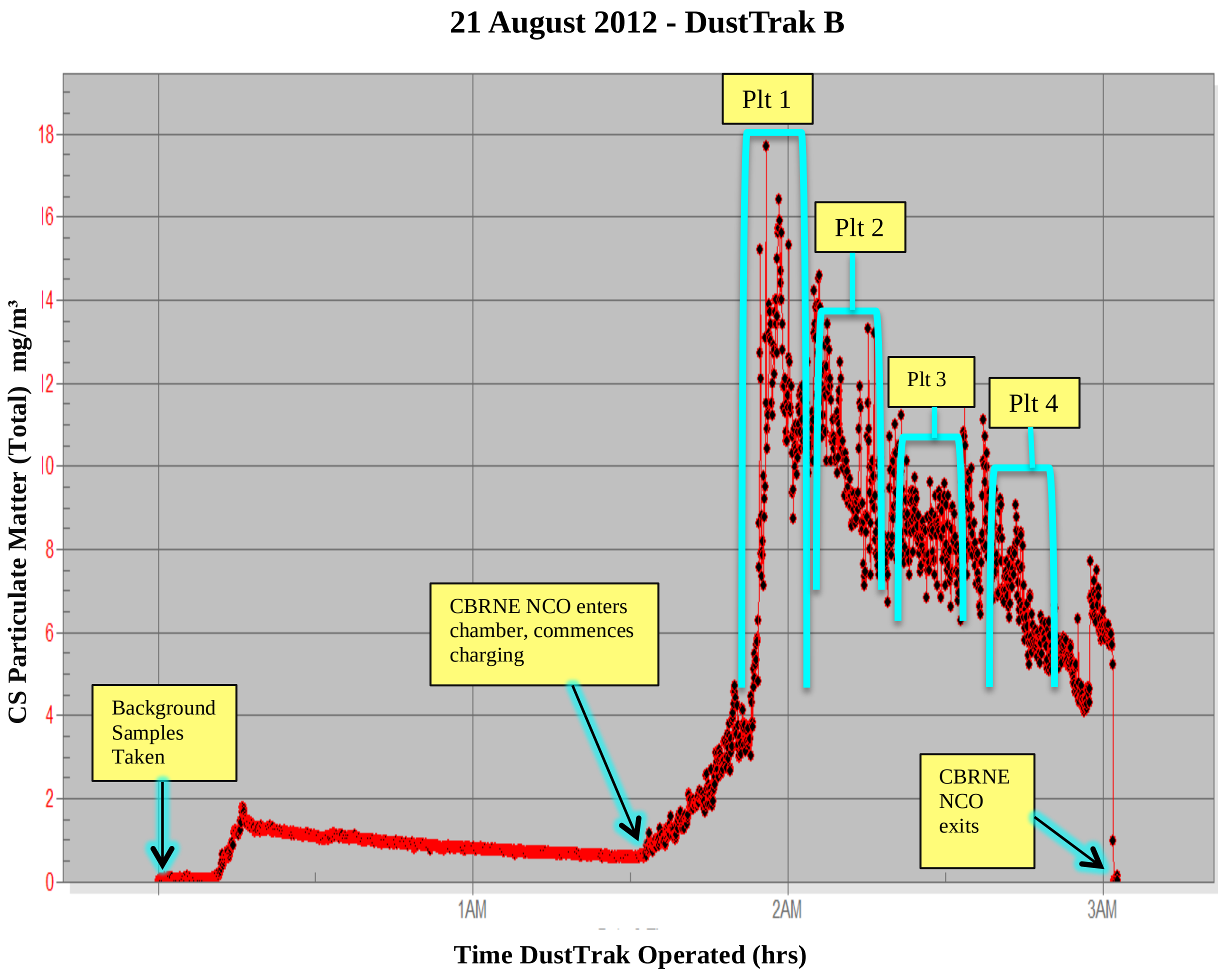


Figure 24B. DustTrak B, sampling when DustTrak A was unserviceable.

Chapter 5: Discussion

COMPARATIVE STUDY

The research objective for the comparative study was to compare the DustTrak CS results to the total concentration of CS determined when using the P&CAM 304 method (case 1); however, due to the fact that the filter portion of P&CAM 304 and the DustTrak were measuring the same phase of CS they were compared separately (case 2). An assumption of the research project prior to the observational study was that the only aerosol-particulate inside the mask confidence chamber was CS.

Results for the DustTrak and fiber filter of the P&CAM 304 represent the aerosol-particulate phase of CS, and thus it was predicted that their concentration results would be comparable. However, based on the results of this study, the DustTrak and P&CAM 304 (filter) were found to be comparable statistically. The Bland-Altman Plots for the comparative study does provide evidence of agreement between the two sampling methods for CS as most of the data points fall within the limits of agreement. However, for the DustTrak and P&CAM 304 (filter) comparison, the limits of agreement from the Bland-Altman Plot were of a very wide range (-29.7 mg/m^3 and 20.5 mg/m^3). These limits of agreement were not a strong agreement level as a measurement made by the DustTrak could differ from the P&CAM 304 (filter) results by as much as 30 mg/m^3 (Figure 18). The limits of agreement suggest poor applicability of theDustTrak when utilized as a direct reading instrument for CS concentration within a CS confidence chamber, as the these values deviate significantly from the ACGIH TLV-C is 0.39 mg/m^3 for CS, and the NIOSH REL-C is 0.40 mg/m^3, as well as the IDLH of 2.0 mg/m^3 (1; 35) . The exposure standards for CS are very small (2 mg/m^3) and having such a wide

range for the limits of agreement (-29.7 to 20.5 mg/m³) between the DustTrak and P&CAM 304 (filter) is not acceptable. The limit of agreement is greater than 10 times the IDLH concentration for CS, thus the margin of human health safety provided when using the DustTrak as a monitoring instrument for CS is debatable.

A potential reason why the DustTrak and P&CAM 304 (filter) are not comparable became evident during the observational study of U.S. recruits undergoing mask confidence chamber training. The DustTrak reports mass measurements from all aerosol-particulates (not CS specific) while the P&CAM 304 (filter) results report mass measurements for CS only. The research assumption was that all aerosol-particulates inside the mask confidence chamber were CS, however, the results being reported by DustTrak indicated otherwise. The fact that the DustTrak measures total aerosol-particulates aids in the explanation as to why there was a weak correlation between it and P&CAM 304 (filter) (Figure 15 and 16). As the DustTrak's concentration averages increased, it did not result in an increase in the P&CAM 304 (filter) CS concentration averages. When the DustTrak reported higher concentration levels, it indicated the possibility of other aerosol-particulates being measured, not higher levels of CS inside the mask confidence chamber. This explanation was supported by the sampling conducted on 24 August 2012 when the mask confidence chamber was swept during charging (Figure 23A). This was the only time that the chamber was swept during the study. The maximum recording from DustTrak A was 148 mg/m³, with the average concentration being 38.1 mg/m³ for 24 August (Figure 23A). By comparison, the average concentration from P&CAM 304 (filter) was 0.39 mg/m³, suggesting that the

DustTrak was also measuring and reporting non-CS aerosol-particulates, in addition to likely re-suspended CS particulates, due to the sweeping.

There were many potential aerosol-particulate sources present in the mask confidence chamber that the DustTrak would detect and measure besides CS. When each platoon entered the chamber, they broughttrack in dust from the outside environment as the entrance way to the chamber consists of a dirt and gravel pathway. Dried vomitus, saliva and mucus were present on the floor of the chamber, as recruits experienced the effects of CS (being a lacrimator and sternutator) when their protective mask was removed (10). The vomitus, saliva and mucus could be re-aerosolized as dried aerosol-particulates. Additionally, the outer casings of the CS capsules and paper were often added to the coffee can to assist in combustion at the CS generating station, producing non-CS aerosol-particulates. All of these sources of non-CS aerosol-particulates were capable of being measured by the DustTrak, unlike when using the P&CAM 304 (filter) method, potentially increasing the overall CS concentration reported by the DustTrak.

Further experiments conducted in support of the comparison study research aim were to compare the results between the DustTrak and the P&CAM 304 (tube and filter) (case 1). The CS concentration averages for P&CAM 304 (tube and filter) and DustTrak A had a p-value that was higher than the set significance level ($0.952 > 0.05$), resulting in the acceptance of the hypothesis that DustTrak A and P&CAM 304 (tube and filter) are comparable. When reviewing the total CS concentration average from all samples for DustTrak A and P&CAM 304 (tube and filter), the values were 8.10 mg/m^3 and 8.22 mg/m^3, respectively. These total CS concentration averages are very close in value and lend support to the paired t-test's results that these two methods of CS sampling are

comparable. However, the limits of agreement between DustTrak A and P&CAM 304 (tube and filter) from the Bland-Altman Plot were - 13.1 mg/m^3 and + 13.3 mg/m^3 (Figure 4). This agreement level, although a smaller range than the filter only portion of P&CAM 304 (-29.7 mg/m^3 to 20.5 mg/m^3), is still not of an acceptable limit when considering the CS occupational exposure regulations. The limit of agreement is greater than 6 times the IDLH concentration for CS, and the appropriateness of using the DustTrak is questionable due to its potential inaccurate characterization of airborne CS concentrations and margin of safety for human health.

The comparable results for the DustTrak and P&CAM 304 (tube and filter) were due to the factmay suggest that a higher proportion of the CS inside the mask confidence chamber was in the vapor phase. The CS concentration from the vapor phase for all samples was 4.7 mg/m^3, compared to aerosol-particulate phase concentration of 3.52 mg/m^3. This finding is consistent with an Australian mask confidence chamber study where the higher proportion of CS was in the vapor phase, and 32-45% of the CS generated for training was emitted in the aerosol-particulate phase (32). The combination of the vapor phase and aerosol-particulate phase of CS results in a higher total CS concentration value. This higher value from P&CAM 304 (tube and filter) would be more comparable to the DustTrak because the DustTrak reports higher concentration averages due to the fact that it is measuring both CS and non-CS aerosol-particulates inside the chamber.

The correlation coefficients (r) for the comparative study were poorly correlated in both instances where DustTrak A was compared to P&CAM 304 (tube and filter) and P&CAM 304 (filter). The correlation coefficients in both cases of the comparative study

increased when transforming the data on the Log10 scale: the P&CAM 304 (tube and filter) value increased from 0.030 to 0.318, and P&CAM 304 (filter) value for r changed from - 0.024 to 0.254. A correlation of 1 indicates perfect positive correlation, absence of correlation at zero, and perfect negative correlation at -1 (18). When values were placed on the Log10 scale, a weak association was found between DustTrak A and P&CAM 304 (tube and filter) and P&CAM304 (filter) as they demonstrated correlation values of 0.318 and 0.254. However, when values are not on the Log10 scale, there is hesitation about assigning an association between the two sampling methods as 0.030 and -0.024 are statistically weak. To base the rejection or acceptance of the hypothesis that the two sampling methods for CS are comparable on the correlation coefficient (r) would be misleading. It is very common for studies to give the correlation coefficient (r) between the results of the two methods measured as an indicator of agreement, but this approach would be incorrect (11). A high correlation does not mean that the two methods agree, nor does a low correlation mean that the two methods do not agree. Correlation measures the strength of the relation (association) between the DustTrak and P&CAM 304, not the agreement between them (11), and this is exactly why the Bland-Altman Plot was required in the comparison study.

ACCUMULATION STUDY

The assessment regarding the accumulation of CS within the confidence chamber over the duration of each training day yielded conflicting results. The Kruskal-Wallis Test results indicated that there was not a statistically significant increase in CS concentration inside the mask confidence chamber when analyzing DustTrak A ($p > 0.05$) results or P&CAM 304 results ($p > 0.05$). However, the Kruskal-Wallis Test results for DustTrak B ($p < 0.05$) indicated that there was a statistically significant

increase in CS concentration in the mask confidence chamber over time, as each platoon completed their training.

A potential reason why the Kruskal-Wallis Test resulted in statistically differing results for DustTrak B relative to DustTrak A and P&CAM 304 could have been due to the location of the instruments inside the mask confidence chamber. DustTrak A was 1.53 meters from the CS generating station towards the exiting side of the chamber, and P&CAM 304 was at a distance of 1.22 meters from the CS generating station towards the chamber exit. DustTrak B was located 1.52 meters away from the CS generating station but towards the entrance way of the chamber (Figure 4). DustTrak A and P&CAM 304 were located in the same area of the chamber and are separated by 31 centimeters (Figure 5).

The Kruskal-Wallis Test assessed DustTrak A and P&CAM 304 separately to investigate if either method indicated CS accumulation over the course of a training day (or total aerosol-particulate accumulation). DustTrak A and P&CAM 304 both conducted their respective sampling concurrently and in the same position. The similar location for DustTrak A and P&CAM 304 could likely be a primary factor in why the Kruskal-Wallis Test yielded similar results for DustTrak A and P&CAM 304.

As previously mentioned, the DustTrak is not CS-specific, but rather, measures total aerosol-particulates, regardless of the source. The Kruskal-Wallis Test results suggest that this non-specificity may have been an additional factor in observing no increase in CS concentration over the duration of a training day when analyzing with DustTrak A, while DustTrak B did demonstrate an increase in total aerosol-particulates as each subsequent platoon in a company completed their mask confidence chamber training.

Explain here what particulates other than CS may have contributed to the overall particulate dose collected by DustTrak B (i.e. explain why you think non-specificity is a factor).

The location of DustTrak A and P&CAM 304 inside the mask confidence chamber assists in attempting to explain why the two had similar results from the Kruskal-Wallis Test. A reason into why CS (or total aerosol-particulates) does not accumulate inside the chamber for DustTrak A and P&CAM 304 may be related to the potential even mixing of the aerosolized CS. DustTrak A and P&CAM 304 were situated towards the exiting end of the chamber where the mask removal procedure occurred for the recruits (Figure 8). This section of the chamber, the exiting end, was observed to receive a higher degree of mixing from the chamber fans. The CBRNE NCO used the small hand-held fan to direct CS from the generating station towards the exiting side of the chamber where the mask removal procedure occurred. The large, stationary fan that was used to disperse CS throughout the chamber was located 0.91 meters from the CS generating station and was located in front of DustTrak B (Figure 8). This large stationary fan was positioned to face towards DustTrak A and P&CAM 304, it did not rotate when operating, and aided in the even mixing of aerosolized CS in the exiting end of the mask confidence chamber.

Another factor that may be a contributing factor in CS not accumulating in the mask confidence chamber was the opening and closing of chamber doors. Chamber doors were opened and closed to allow platoons to enter and exit the chamber, which potentially assisted in the even mixing of the aerosolized CS throughout the chamber. Chamber doors were kept closed during mask confidence chamber training, but were

often opened if a recruit had mask issues and needed to leave the chamber. This could have potentially aided in the mixing and even distribution of CS throughout the chamber, and resulted in CS not accumulating as each platoon in a company completed mask confidence chamber training.

The Kruskal-Wallis Test for DustTrak B had a p-value < 0.05 and rejected the hypothesis that CS distribution (increase in airborne CS concentration over time) would be the same across platoons (Figure 21A). When the different samples (platoon groups) were compared to each other, platoon 1 had statistically significant lower average aerosol-particulate concentrations than platoon 3 and platoon 4 (Figure 21B). There are many potential reasons why DustTrak B had higher total aerosol-particulate concentration measurements for platoon 3 and platoon 4. DustTrak B was located near the entrance way of the chamber where the recruits entered, and a greater amount of dirt and dust being brought into the chamber would occur here. The large stationary fan was in front of DustTrak B (facing away from it), and blew the air towards DustTrak A and P&CAM 304. The CBRNE NCO also focused the majority of the hand held fan assisted dispersal of the aerosolized CS towards the exiting end of the chamber where the recruits conducted their mask removal procedure. The operation of the two fans being focused towards the exiting end of the chamber potentially resulted in air pockets and poor mixing at the entrance way of the chamber. Furthermore, as each platoon entered the chamber and completed their training, there was more vomit, mucus and salivia on the chamber floor that may be re-aerosolized.

LIMITATIONS

The comparative study between the DustTrak and the OSHA modified NIOSH P&CAM 304 for CS sampling and the CS accumulation study were both observational

studies. The CS sampling conducted for this research was completed during mask confidence chamber training for U.S. Army recruits, and at no time was there actual or suggested interference in the operating procedures for the chamber. The observational study approach to the research did present some limitations in attempting to manage potential study confounders.

The actual burning of the CS was identified as a potential confounder in this study. There were a great deal of differences observed in how the training CBRNE NCOs generated the CS. Specifically, the charging of the chamber presented many discrepancies; some CBRNE NCOs used the paper, while others only used a portion of it or none at all. Given this, depending on who charged the chamber, the potential for some initial non-CS particulate matter to be emitted into the chamber air existed. The CBRNE NCOs also differed in that some instructors added the CS capsule casing to the coffee can during the burning of CS while others opened the capsules and only poured in the CS granules into the coffee can. Again, having the CS capsule included in the burning procedure of CS would cause the DustTrak to have higher readings as it would measure this non-CS aerosol-particulate.

The use of small hand-held fan and larger stationary fan inside the chamber also represented a potential factor impacting study results, as some of the CBRNE NCO would use the small fan more than others to direct the CS towards the exiting end of the chamber. It was also noted during the sampling period that some of the CBRNE NCOs did not use the large fan, and it remained off during the entire time training was being conducted. The discrepancy in fan usage would impact the results of the accumulation

study, as much of the results are explained by assisted air distribution inside the mask confidence chamber.

In addition to the mask confidence chamber's operating procedures potentially impacting study results, the training schedule for the chamber could also be considered as such. Mask confidence chamber training occurred in the early morning, mid-morning, or afternoon depending on the set schedule. As previously mentioned, the average daily temperature was 82.3 F (27.9 °C), with a low of 74.7 F (23. 7°C) and a high of 84.4 F (29.1°C), and the average relative humidity was 72.2% for the sampling period. The time of day that mask confidence chamber training was conducted likely influenced what phase the CS was in. Training conducted in the morning had lower temperatures than afternoon training, and a higher amount of CS could have remained in the vapor phase with the higher afternoon temperatures. The fact that the training schedule for the chamber was not altered by the researcher, and the variation in time in which sampling occurred was a limiting factor for the study. Another time factor that influenced the sampling was the time between charging the chamber with CS, and when the first platoon entered the chamber for training. Some of the companies would get to the mask confidence chamber range and decide to have their platoons eat breakfast. This delay in the training schedule was not always communicated to the training CBRNE NCOs. The chamber in some instances was already charged and had to wait for platoons to enter. The time spent waiting for platoons to enter the chamber would have also impacted what phase the CS was in.

The DustTrak instrument itself had a limiting factor. The DustTrak manufacturer's recommended maintenance schedule for cleaning the sample inlet is

every 350 hours at 1 mg/m^3. This maintenance recommendation should be modified according to frequency of instrument use and airborne concentration, for instance 700 hours at 0.5 mg/m^3, and 175 hours at 2 mg/m^3 (48) . The average airborne concentration of CS inside the mask confidence chamber was measured to be much higher than these values, and the average amount of aerosol-particulates that the DustTrak measured was 8.10 mg/m^3. At this level of aerosol-particulate, the DustTrak's inlet sample tube would have to be cleaned after 43.75 hours of operation. This interesting finding was not discovered until sampling had started, as it was unknown what the aerosol-particulate level within the chamber would be prior to sampling. On the 6th day of sampling with DustTrak A, equating to an operational run time of 15.13 hours, DustTrak A became unserviceable (Figure 14A) due to the sample inlet becoming clogged. Based on the recommended maintenance schedule, the DustTrak had been operating for 15.13 hours at that point andsupposedly had 28.62 hours before it was due to be cleaned at that point. This finding should be noted for current and future users of the DustTrak instrument when conducting sampling in relatively high airborne particulate concentrations, similar to mask confidence chamber training. This unscheduled maintenance and cleaning of the DustTrak's inlet resulted in a day of sampling being compromised. After this event, both DustTrak A and DustTrak B were cleaned daily, resulting in no additional clogging issues for the remainder of the study.

Chapter 6: Conclusion and Future

CONCLUSION

This research compared the non-specific, photometric particle counting instrument, DustTrak, which provides real time results, to the OSHA modified NIOSH P&CAM 304 method, which is specific for CS vapor and aerosol-particulate and requires subsequent laboratory analysis, during mask confidence training for U.S Army recruits. This comparison study was conducted in order to determine correlation, if any, between the DustTrak and P&CAM 304. This research also investigated CS accumulation inside the mask confidence chamber throughout the duration of a training day, and if recruits undergoing mask confidence training were exposed to different CS concentrations depending on the sequence in which they complete their training.

DustTrak and P&CAM 304 method results were compared using paired t-test, correlation coefficient, and Bland-Altman limits of agreement. While the methods were found to be comparable ($p>0.05$), they showed weak positive correlation ($r = 0.03$). Additionally, the statistical comparison identified limits of agreement with large ranges (-29.7 to 20.5 mg/m³ (filter) and -13.1 to 13.3 mg/m³ (filter/tube)) relative to established occupational health limits and guidelines. The limits of agreement ranges exceeded the CS occupational exposure standard for immediately dangerous to life and health (IDLH) concentration of 2 mg/m³.

It cannot be assumed that the DustTrak and the OSHA modified NIOSH P&CAM 304 are comparable methods for CS sampling. While the DustTrak is potentially well-suited to non-specific dusty environments, as demonstrated by the instrument's performance on 24 August 2012 when the chamber was swept and resulted in an

extremely dusty environment (Figure 23), it is not well correlated to the established laboratory accepted standard for airborne CS concentration analysis. Therefore, the DustTrak would not be recommended as a real time analyzer of CS during mask confidence training.

The results from DustTrak A, P&CAM 304, and DustTrak B were analyzed with the Kruskal-Wallis Test to assess CS accumulation inside the mask confidence chamber. The CS concentration data from DustTrak A and P&CAM 304 indicated that there was not an increase of CS concentration inside the mask confidence chamber throughout the duration of a training day. DustTrak B, however, did produce results that indicated that an increase of non-specific aerosol-particulates inside the mask confidence chamber did occur. Thus, it can be assumed that when utilizing similar procedures and chamber volume, CS concentration inside the mask confidence chamber does not increase over the duration of a training day, and recruits undergoing mask confidence training are not exposed to statistically different CS concentrations regardless of the sequence in which they complete their training.

FUTURE RESEARCH

Further research is required to validate the DustTrak method as a real time monitor of CS aerosol-particulates. Previous research validated the DustTrak method as a potentially effective monitoring device for CS but did so under controlled laboratory settings, and validated the DustTrak against gravimetric sampling (32). Experiments conducted under controlled laboratory conditions, or simulated mask confidence chamber training, comparing the DustTrak to the OSHA modified NIOSH P&CAM 304 method could potentially produce a stronger correlation between the two methods. A comparison study between the DustTrak and gravimetric sampling during mask confidence training,

simulated mask confidence training, and/or controlled laboratory conditions would provide information as to if the DustTrak is comparable to another sampling method (gravimetric sampling vice P&CAM 304 sampling).

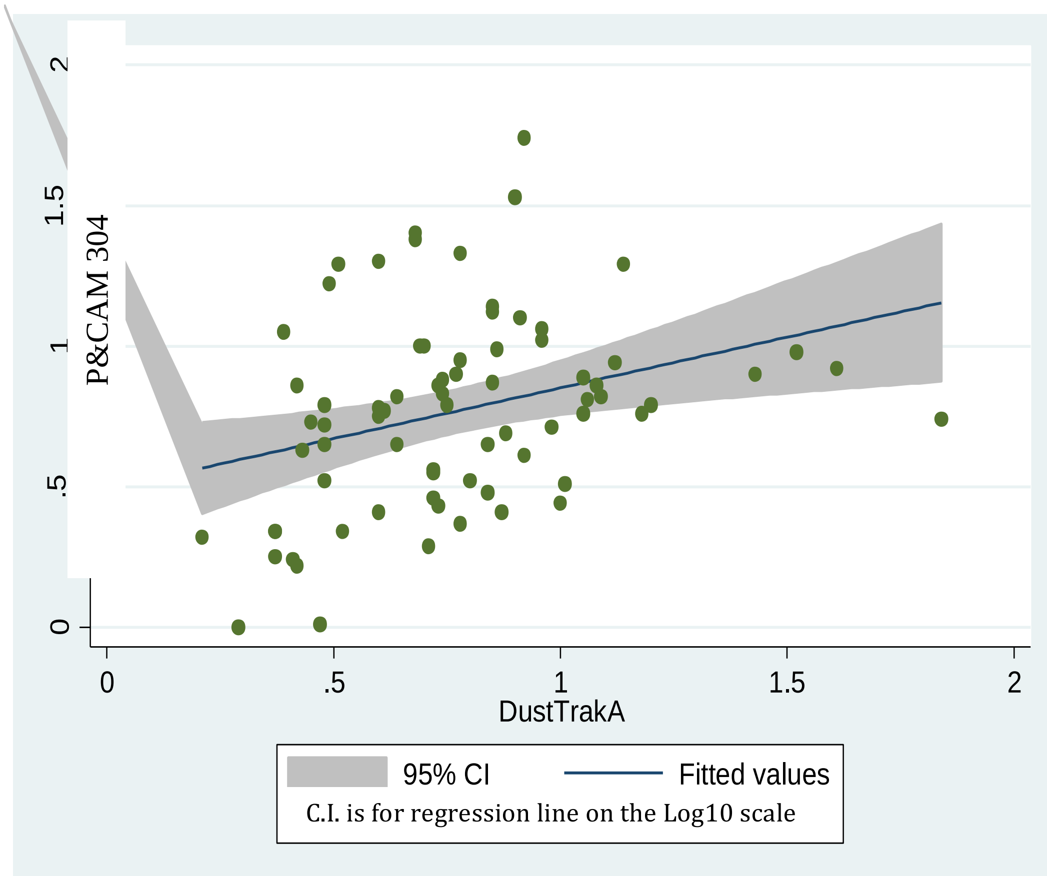
There were a number of limiting factors for this study, and repeating the observational study at Fort Jackson between the DustTrak and P&CAM 304 with some modifications would be warranted. If the researchers could sample at the same time every day, have consistent timings between charging the chamber with CS and training, and measure the air flow inside the chamber, then a better assessment into the correlation between the two sampling methods could be made.

APPENDICES

Appendix A. CS concentration DustTrak A and P&CAM 304 (tube/filter)

Sample	DustTrak A Final Daily PM Avg mg/m³	P&CAM 304 Final Daily PM Avg (tube/filter) mg/m³	DustTrak A Final Daily PM Avg mg/m³ Log10	P&CAM 304 Final Daily PM Avg (tube/filter) mg/m³ Log10
1) 20/08/12 Plt 1	13.7	19.4	1.14	1.29
2) 20/08/12 Plt 2	8.01	33.8	0.90	1.53
3) 20/08/12 Plt 3	8.40	55.0	0.92	1.74
4) 20/08/12 Plt 4	5.51	7.62	0.74	0.88
5) 20/08/12 NCO	6.07	21.2	0.78	1.33
6) 22/08/12 Plt 1 C1	3.98	20.1	0.60	1.30
7) 22/08/12 Plt 2 C1	4.82	25.0	0.68	1.40
8) 22/08/12 Plt 3 C1	4.83	24.1	0.68	1.38
9) 22/08/12 Plt 4 C1	3.08	16.6	0.49	1.22
10) 22/08/12 NCO C1	3.24	19.5	0.51	1.29
11) 22/08/12 Plt 1 C2	2.67	4.22	0.43	0.63
12) 22/08/12 Plt 2 C2	3.01	4.52	0.48	0.65
13) 22/08/12 Plt 3 C2	3.05	5.23	0.48	0.72
14) 22/08/12 Plt 4 C2	2.80	5.32	0.45	0.73
15) 22/08/12 NCO C2	2.61	7.29	0.42	0.86
16) 24/08/12 Plt 1	69.3	5.51	1.84	0.74
17) 24/08/12 Plt 2	40.3	8.24	1.61	0.92
18) 24/08/12 Plt 3	26.9	7.87	1.43	0.90
19) 24/08/12 Plt 4	15.8	6.16	1.20	0.79
20) 24/08/12 NCO	33.4	9.48	1.52	0.98
21) 27/08/12 Plt 1	3.01	6.10	0.48	0.79
22) 27/08/12 Plt 2	4.08	5.89	0.61	0.77
23) 27/08/12 Plt 3	3.98	5.62	0.60	0.75
24) 27/08/12 NCO	2.47	11.3	0.39	1.05
25) 29/08/12 Plt 1 C1	3.03	3.34	0.48	0.52
26) 29/08/12 Plt 2 C1	3.97	2.58	0.60	0.41
27) 29/08/12 Plt 3 C1	3.31	2.18	0.52	0.34
28) 29/08/12 Plt 4 C1	2.64	1.67	0.42	0.22
29) 29/08/12 NCO C1	2.95	1.03	0.47	0.01
30) 29/08/12 Plt 1 C2	1.63	2.10	0.21	0.32
31) 29/08/12 Plt 2 C2	2.36	2.18	0.37	0.34
32) 29/08/12 Plt 3 C2	2.35	1.79	0.37	0.25
33) 29/08/12 Plt 4 C2	2.35	2.18	0.37	0.34
34) 29/08/12 NCO C2	1.94	0.99	0.29	0.00
35) 5/09/12 Plt 1 C1	3.97	6.00	0.60	0.78
36) 5/09/12 Plt 2 C1	5.20	2.86	0.72	0.46
37) 5/09/12 Plt 3 C1	6.34	3.34	0.80	0.52
38) 5/09/12 Plt 4 C1	6.85	3.00	0.84	0.48
39) 5/09/12 NCO C1	4.85	10.0	0.69	1.00
40) 5/09/12 Plt 1 C2	2.54	1.74	0.41	0.24
41) 5/09/12 Plt 2 C2	4.34	4.43	0.64	0.65
42) 5/09/12 Plt 3 C2	9.62	5.11	0.98	0.71
43) 5/09/12 Plt 4 C2	10.1	2.78	1.00	0.44
44) 5/09/12 NCO C2	5.24	3.60	0.72	0.56
45) 7/09/12 Plt 1 C1	7.50	4.95	0.88	0.69
46) 7/09/12 Plt 2 C1	6.85	4.45	0.84	0.65
47) 7/09/12 Plt 3 C1	7.44	2.57	0.87	0.41
48) 7/09/12 Plt 4 C1	8.26	4.09	0.92	0.61
49) 7/09/12 NCO C1	6.05	2.36	0.78	0.37
50) 7/09/12 Plt 1 C2	6.01	8.82	0.78	0.95
51) 7/09/12 Plt 2 C2	5.92	7.97	0.77	0.90
52) 7/09/12 Plt 3 C2	5.34	7.29	0.73	0.86
53) 7/09/12 Plt 4 C2	4.35	6.59	0.64	0.82
54) 7/09/12 NCO C2	5.01	10.1	0.70	1.00
55) 11/09/12 Plt 1	5.23	3.59	0.72	0.55
56) 11/09/12 Plt 2	9.16	11.4	0.96	1.06
57) 11/09/12 Plt 3	11.2	7.74	1.05	0.89
58) 11/09/12 Plt 4	10.2	3.24	1.01	0.51
59) 11/09/12 NCO	7.17	9.87	0.86	0.99
60) 12/09/12 Plt 1 C1	5.17	1.94	0.71	0.29
61) 12/09/12 Plt 2 C1	11.3	5.70	1.05	0.76
62)12/09/12 Plt 3 C1	15.1	5.74	1.18	0.76
63) 12/09/12 Plt 4 C1	13.2	8.63	1.12	0.94
64) 12/09/12 NCO C1	8.21	12.7	0.91	1.10
65) 12/09/12 Plt 1 C2	5.39	2.67	0.73	0.43
66) 12/09/12 Plt 2 C2	7.15	13.1	0.85	1.12
67) 12/09/12 Plt 3 C2	7.06	13.9	0.85	1.14
68) 12/09/12 Plt 4 C2	7.09	7.48	0.85	0.87
69) 12/09/12 NCO C2	5.56	6.10	0.75	0.79
70) 14/09/12 Plt 1	5.50	6.73	0.74	0.83
71) 14/09/12 Plt 2	11.5	6.44	1.06	0.81
72) 14/09/12 Plt 3	12.4	6.59	1.09	0.82
73) 14/09/12 Plt 4	12.0	7.21	1.08	0.86
74) 14/09/12 NCO	9.04	10.5	0.96	1.02

APPENDIX B. 95% C.I. FOR REGRESSION LINE, (TUBE/FILTER)



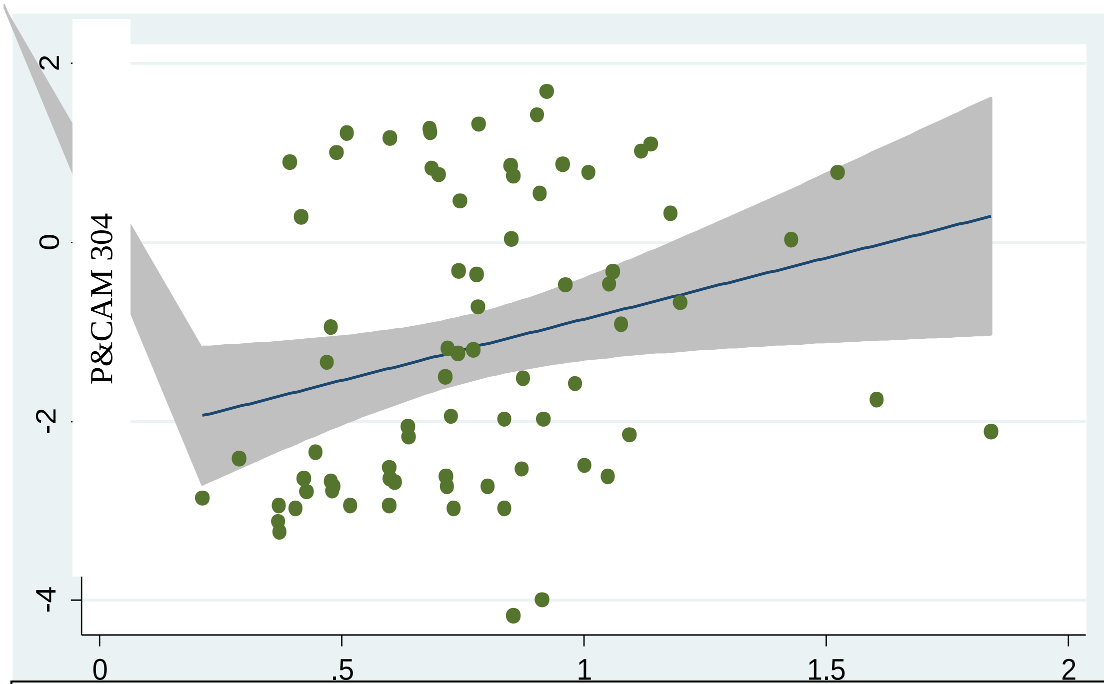
APPENDIX C. CS CONCENTRATIONS FOR DUSTTRAK A AND P&CAM 304 (TUBE/FILTER) WITH BLAND-ALTMAN STATISTICS

Sample	DustTrak A Final Daily PM Avg mg/m^3	P&CAM 304 Final Daily PM Avg (tube/filter) mg/m^3	Average DustTrak A and P&CAM 304 mg/m^3	Difference P&CAM 304 and DustTrak A mg/m^3
1) 20/08/12 Plt 1	13.7	19.4	16.5	5.62
2) 20/08/12 Plt 2	8.01	33.8	20.9	25.8
3) 20/08/12 Plt 3	8.40	55.0	31.7	46.6
4) 20/08/12 Plt 4	5.51	7.62	6.56	2.11
5) 20/08/12 NCO	6.07	21.2	13.7	15.2
6) 22/08/12 Plt 1 C1	3.98	20.1	12.0	16.1
7) 22/08/12 Plt 2 C1	4.82	25.0	14.9	20.2
8) 22/08/12 Plt 3 C1	4.83	24.1	14.5	19.3
9) 22/08/12 Plt 4 C1	3.08	16.6	9.83	13.5
10) 22/08/12 NCO C1	3.24	19.5	11.4	16.3
11) 22/08/12 Plt 1 C2	2.67	4.22	3.45	1.54
12) 22/08/12 Plt 2 C2	3.01	4.52	3.76	1.50
13) 22/08/12 Plt 3 C2	3.05	5.23	4.14	2.19
14) 22/08/12 Plt 4 C2	2.80	5.32	4.06	2.52
15) 22/08/12 NCO C2	2.61	7.29	4.95	4.67
16) 24/08/12 Plt 1	69.3	5.51	37.4	-63.8
17) 24/08/12 Plt 2	40.3	8.24	24.3	-32.1
18) 24/08/12 Plt 3	26.9	7.87	17.4	-19.0
19) 24/08/12 Plt 4	15.8	6.16	11.0	-9.67
20) 24/08/12 NCO	33.4	9.48	21.5	-24.0
21) 27/08/12 Plt 1	3.01	6.10	4.56	3.08
22) 27/08/12 Plt 2	4.08	5.89	4.98	1.81
23) 27/08/12 Plt 3	3.98	5.62	4.80	1.63
24) 27/08/12 NCO	2.47	11.3	6.90	8.86
25) 29/08/12 Plt 1 C1	3.03	3.34	3.18	0.31
26) 29/08/12 Plt 2 C1	3.97	2.58	3.27	-1.40
27) 29/08/12 Plt 3 C1	3.31	2.18	2.75	-1.12
28) 29/08/12 Plt 4 C1	2.64	1.67	2.16	-0.97
29) 29/08/12 NCO C1	2.95	1.03	1.99	-1.92
30) 29/08/12 Plt 1 C2	1.63	2.10	1.87	0.47
31) 29/08/12 Plt 2 C2	2.36	2.18	2.27	-0.17
32) 29/08/12 Plt 3 C2	2.35	1.79	2.07	-0.56
33) 29/08/12 Plt 4 C2	2.35	2.18	2.26	-0.16
34) 29/08/12 NCO C2	1.94	0.99	1.47	-0.95
35) 5/09/12 Plt 1 C1	3.97	6.00	4.99	2.04
36) 5/09/12 Plt 2 C1	5.20	2.86	4.03	-2.34
37) 5/09/12 Plt 3 C1	6.34	3.34	4.84	-3.01
38) 5/09/12 Plt 4 C1	6.85	3.00	4.93	-3.85
39) 5/09/12 NCO C1	4.85	10.0	7.42	5.15
40) 5/09/12 Plt 1 C2	2.54	1.74	2.14	-0.81
41) 5/09/12 Plt 2 C2	4.34	4.43	4.38	0.09
42) 5/09/12 Plt 3 C2	9.62	5.11	7.37	-4.51
43) 5/09/12 Plt 4 C2	10.1	2.78	6.42	-7.27
44) 5/09/12 NCO C2	5.24	3.60	4.42	-1.65
45) 7/09/12 Plt 1 C1	7.50	4.95	6.22	-2.56
46) 7/09/12 Plt 2 C1	6.85	4.45	5.65	-2.40
47) 7/09/12 Plt 3 C1	7.44	2.57	5.00	-4.88
48) 7/09/12 Plt 4 C1	8.26	4.09	6.17	-4.16
49) 7/09/12 NCO C1	6.05	2.36	4.21	-3.68
50) 7/09/12 Plt 1 C2	6.01	8.82	7.41	2.81
51) 7/09/12 Plt 2 C2	5.92	7.97	6.94	2.05
52) 7/09/12 Plt 3 C2	5.34	7.29	6.31	1.95
53) 7/09/12 Plt 4 C2	4.35	6.59	5.47	2.25
54) 7/09/12 NCO C2	5.01	10.1	7.55	5.06
55) 11/09/12 Plt 1	5.23	3.59	4.41	-1.64
56) 11/09/12 Plt 2	9.16	11.4	10.3	2.25
57) 11/09/12 Plt 3	11.2	7.74	9.48	-3.48
58) 11/09/12 Plt 4	10.2	3.24	6.73	-6.98
59) 11/09/12 NCO	7.17	9.87	8.52	2.70
60) 12/09/12 Plt 1 C1	5.17	1.94	3.56	-3.23
61) 12/09/12 Plt 2 C1	11.3	5.70	8.50	-5.61
62) 12/09/12 Plt 3 C1	15.1	5.74	10.42	-9.37
63) 12/09/12 Plt 4 C1	13.2	8.63	10.9	-4.52
64) 12/09/12 NCO C1	8.21	12.7	10.5	4.50
65) 12/09/12 Plt 1 C2	5.39	2.67	4.03	-2.72
66) 12/09/12 Plt 2 C2	7.15	13.1	10.1	5.93
67) 12/09/12 Plt 3 C2	7.06	13.9	10.5	6.88
68) 12/09/12 Plt 4 C2	7.09	7.48	7.29	0.38
69) 12/09/12 NCO C2	5.56	6.10	5.83	0.54
70) 14/09/12 Plt 1	5.50	6.73	6.11	1.23
71) 14/09/12 Plt 2	11.5	6.44	8.96	-5.05
72) 14/09/12 Plt 3	12.4	6.59	9.50	-5.82
73) 14/09/12 Plt 4	12.0	7.21	9.59	-4.77
74) 14/09/12 NCO	9.04	10.5	9.78	1.48

Appendix D. CS concentrations with DustTrak A and P&CAM 304 (filter)

Sample	DustTrak A Final Daily PM Avg mg/m^3	P&CAM 304 Final Daily PM Avg (filter) mg/m^3	DustTrak A Final Daily PM Avg mg/m^3 Log10	P&CAM 304 Final Daily PM Avg (filter) mg/m^3 Log10	Sample	DustTrak A Final Daily PM Avg mg/m^3	P&CAM 304 Final Daily PM Avg (filter) mg/m^3	DustTrak A Final Daily PM Avg mg/m^3 Log10	P&CAM 304 Final Daily PM Avg (filter) mg/m^3 Log10
1) 20/08/12 Plt 1	13.7	12.59	1.14	1.10	40) 5/09/12 Plt 1 C2	2.54	0.001	0.41	-2.97
2) 20/08/12 Plt 2	8.01	26.66	0.90	1.43	41) 5/09/12 Plt 2 C2	4.34	0.009	0.64	-2.06
3) 20/08/12 Plt 3	8.40	48.25	0.92	1.68	42) 5/09/12 Plt 3 C2	9.62	0.026	0.98	-1.58
4) 20/08/12 Plt 4	5.51	0.478	0.74	-0.32	43) 5/09/12 Plt 4 C2	10.1	0.003	1.00	-2.49
5) 20/08/12 NCO	6.07	20.74	0.78	1.32	44) 5/09/12 NCO C2	5.24	0.066	0.72	-1.18
6) 22/08/12 Plt 1 C1	3.98	0.008	0.60	-2.12	45) 7/09/12 Plt 1 C1	7.50	0.031	0.88	-1.52
7) 22/08/12 Plt 2 C1	4.82	0.017	0.68	-1.76	46) 7/09/12 Plt 2 C1	6.85	0.010	0.84	-1.98
8) 22/08/12 Plt 3 C1	4.83	1.077	0.68	0.03	47) 7/09/12 Plt 3 C1	7.44	0.003	0.87	-2.53
9) 22/08/12 Plt 4 C1	3.08	0.211	0.49	-0.68	48) 7/09/12 Plt 4 C1	8.26	0.011	0.92	-1.98
10) 22/08/12 NCO C1	3.24	5.998	0.51	0.78	49) 7/09/12 NCO C1	6.05	0.188	0.78	-0.72
11) 22/08/12 Plt 1 C2	2.67	14.66	0.43	1.17	50) 7/09/12 Plt 1 C2	6.01	0.436	0.78	-0.36
12) 22/08/12 Plt 2 C2	3.01	18.66	0.48	1.27	51) 7/09/12 Plt 2 C2	5.92	0.063	0.77	-1.20
13) 22/08/12 Plt 3 C2	3.05	17.03	0.48	1.23	52) 7/09/12 Plt 3 C2	5.34	0.011	0.73	-1.95
14) 22/08/12 Plt 4 C2	2.80	9.998	0.45	1.00	53) 7/09/12 Plt 4 C2	4.35	0.007	0.64	-2.18
15) 22/08/12 NCO C2	2.61	16.86	0.42	1.23	54) 7/09/12 NCO C2	5.01	5.689	0.70	0.76
16) 24/08/12 Plt 1	69.3	0.002	1.84	-2.79	55) 11/09/12 Plt 1	5.23	0.002	0.72	-2.73
17) 24/08/12 Plt 2	40.3	0.002	1.61	-2.67	56) 11/09/12 Plt 2	9.16	0.331	0.96	-0.48
18) 24/08/12 Plt 3	26.9	0.002	1.43	-2.73	57) 11/09/12 Plt 3	11.2	0.002	1.05	-2.61
19) 24/08/12 Plt 4	15.8	0.005	1.20	-2.34	58) 11/09/12 Plt 4	10.2	5.998	1.01	0.78
20) 24/08/12 NCO	33.4	1.921	1.52	0.28	59) 11/09/12 NCO	7.17	0.000	0.86	-4.18
21) 27/08/12 Plt 1	3.01	0.113	0.48	-0.95	60) 12/09/12 Plt 1 C1	5.17	0.031	0.71	-1.51
22) 27/08/12 Plt 2	4.08	0.002	0.61	-2.68	61) 12/09/12 Plt 2 C1	11.3	0.338	1.05	-0.47
23) 27/08/12 Plt 3	3.98	0.002	0.60	-2.64	62) 12/09/12 Plt 3 C1	15.1	2.116	1.18	0.33
24) 27/08/12 NCO	2.47	7.970	0.39	0.90	63) 12/09/12 Plt 4 C1	13.2	10.41	1.12	1.02
25) 29/08/12 Plt 1 C1	3.03	0.002	0.48	-2.78	64) 12/09/12 NCO C1	8.21	0.000	0.91	-4.00
26) 29/08/12 Plt 2 C1	3.97	0.001	0.60	-2.94	65) 12/09/12 Plt 1 C2	5.39	0.001	0.73	-2.97
27) 29/08/12 Plt 3 C1	3.31	0.001	0.52	-2.94	66) 12/09/12 Plt 2 C2	7.15	5.458	0.85	0.74
28) 29/08/12 Plt 4 C1	2.64	0.002	0.42	-2.64	67) 12/09/12 Plt 3 C2	7.06	7.271	0.85	0.86
29) 29/08/12 NCO C1	2.95	0.045	0.47	-1.34	68) 12/09/12 Plt 4 C2	7.09	1.099	0.85	0.04
30) 29/08/12 Plt 1 C2	1.63	0.001	0.21	-2.86	69) 12/09/12 NCO C2	5.56	2.909	0.75	0.46
31) 29/08/12 Plt 2 C2	2.36	0.001	0.37	-3.23	70) 14/09/12 Plt 1	5.50	0.057	0.74	-1.24
32) 29/08/12 Plt 3 C2	2.35	0.001	0.37	-2.94	71) 14/09/12 Plt 2	11.5	0.474	1.06	-0.32
33) 29/08/12 Plt 4 C2	2.35	0.001	0.37	-3.12	72) 14/09/12 Plt 3	12.4	0.007	1.09	-2.15
34) 29/08/12 NCO C2	1.94	0.004	0.29	-2.42	73) 14/09/12 Plt 4	12.0	0.123	1.08	-0.91
35) 5/09/12 Plt 1 C1	3.97	0.003	0.60	-2.52	74) 14/09/12 NCO	9.04	7.465	0.96	0.87
36) 5/09/12 Plt 2 C1	5.20	0.002	0.72	-2.61					
37) 5/09/12 Plt 3 C1	6.34	0.002	0.80	-2.73					
38) 5/09/12 Plt 4 C1	6.85	0.001	0.84	-2.97					
39) 5/09/12 NCO C1	4.85	6.665	0.69	0.82					

APPENDIX E. 95% C.I. FOR REGRESSION LINE (FILTER)



95% C.I. for Regression Line

APPENDIX F. CS CONCENTRATIONS FOR DUSTTRAK A AND P&CAM 304 (FILTER) WITH BLAND-ALTMAN STATISTICS

Sample	DustTrak A Final Daily PM Avg mg/m^3	P&CAM 304 Final Daily PM Avg (filter) mg/m^3	Average DustTrak A and P&CAM 304 mg/m^3	Difference P&CAM 304 and DustTrak A (filter) mg/m^3	Sample	DustTrak A Final Daily PM Avg mg/m^3	P&CAM 304 Final Daily PM Avg (filter) mg/m^3	Average DustTrak A and P&CAM 304 mg/m^3	Difference P&CAM 304 and DustTrak A mg/m^3
1) 20/08/12 Plt 1	13.73	12.59	13.16	-1.144	38) 5/09/12 Plt 4 C1	6.849	0.001	3.425	-6.848
2) 20/08/12 Plt 2	8.010	26.66	17.34	18.65	39) 5/09/12 NCO C1	4.848	6.665	5.756	1.816
3) 20/08/12 Plt 3	8.400	48.25	28.33	39.85	40) 5/09/12 Plt 1 C2	2.542	0.001	1.272	-2.541
4) 20/08/12 Plt 4	5.507	0.478	2.992	-5.029	41) 5/09/12 Plt 2 C2	4.339	0.009	2.174	-4.330
5) 20/08/12 NCO	6.068	20.74	13.40	14.67	42) 5/09/12 Plt 3 C2	9.625	0.026	4.826	-9.599
6) 22/08/12 Plt 1 C1	69.30	0.008	34.66	-69.30	43) 5/09/12 Plt 4 C2	10.05	0.003	5.028	-10.050
7) 22/08/12 Plt 2 C1	40.31	0.017	20.17	-40.30	44) 5/09/12 NCO C2	5.241	0.066	2.654	-5.175
8) 22/08/12 Plt 3 C1	26.88	1.077	13.98	-25.80	45) 7/09/12 Plt 1 C1	7.501	0.031	3.766	-7.470
9) 22/08/12 Plt 4 C1	15.83	0.211	8.019	-15.62	46) 7/09/12 Plt 2 C1	6.849	0.010	3.429	-6.838
10) 22/08/12 NCO C1	33.43	5.998	19.71	-27.43	47) 7/09/12 Plt 3 C1	7.442	0.003	3.723	-7.439
11) 22/08/12 Plt 1 C2	3.979	14.66	9.32	10.69	48) 7/09/12 Plt 4 C1	8.256	0.011	4.133	-8.246
12) 22/08/12 Plt 2 C2	4.818	18.66	11.74	13.85	49) 7/09/12 NCO C1	6.048	0.188	3.118	-5.859
13) 22/08/12 Plt 3 C2	4.829	17.03	10.93	12.21	50) 7/09/12 Plt 1 C2	6.007	0.436	3.222	-5.571
14) 22/08/12 Plt 4 C2	3.081	10.00	6.540	6.917	51) 7/09/12 Plt 2 C2	5.920	0.063	2.991	-5.857
15) 22/08/12 NCO C2	3.241	16.86	10.05	13.62	52) 7/09/12 Plt 3 C2	5.337	0.011	2.674	-5.326
16) 24/08/12 Plt 1	2.674	0.002	1.338	-2.672	53) 7/09/12 Plt 4 C2	4.346	0.007	2.176	-4.340
17) 24/08/12 Plt 2	3.013	0.002	1.508	-3.011	54) 7/09/12 NCO C2	5.013	5.689	5.351	0.676
18) 24/08/12 Plt 3	3.047	0.002	1.525	-3.045	55) 11/09/12 Plt 1	5.225	0.002	2.614	-5.223
19) 24/08/12 Plt 4	2.799	0.005	1.402	-2.795	56) 11/09/12 Plt 2	9.159	0.331	4.745	-8.828
20) 24/08/12 NCO	2.615	1.921	2.268	-0.694	57) 11/09/12 Plt 3	11.22	2E-03	5.611	-11.22
21) 27/08/12 Plt 1	3.014	0.113	1.564	-2.901	58) 11/09/12 Plt 4	10.22	6E+00	8.110	-4.225
22) 27/08/12 Plt 2	4.077	0.002	2.040	-4.075	59) 11/09/12 NCO	7.167	7E-05	3.584	-7.167
23) 27/08/12 Plt 3	3.982	0.002	1.992	-3.980	60) 12/09/12 Plt 1 C1	5.172	0.031	2.602	-5.141
24) 27/08/12 NCO	2.472	7.970	5.221	5.498	61) 12/09/12 Plt 2 C1	11.31	0.338	5.823	-10.97
25) 29/08/12 Plt 1 C1	3.028	0.002	1.515	-3.026	62) 12/09/12 Plt 3 C1	15.11	2.116	8.610	-12.99
26) 29/08/12 Plt 2 C1	3.973	0.001	1.987	-3.972	63) 12/09/12 Plt 4 C1	13.15	10.41	11.78	-2.736
27) 29/08/12 Plt 3 C1	3.307	0.001	1.654	-3.306	64) 12/09/12 NCO C1	8.212	1E-04	4.106	-8.212
28) 29/08/12 Plt 4 C1	2.645	0.002	1.324	-2.642	65) 12/09/12 Plt 1 C2	5.389	0.001	2.695	-5.388
29) 29/08/12 NCO C1	2.949	0.045	1.497	-2.904	66) 12/09/12 Plt 2 C2	7.146	5.458	6.302	-1.688
30) 29/08/12 Plt 1 C2	1.634	0.001	0.818	-1.633	67) 12/09/12 Plt 3 C2	7.059	7.271	7.165	0.212
31) 29/08/12 Plt 2 C2	2.356	0.001	1.178	-2.355	68) 12/09/12 Plt 4 C2	7.094	1.099	4.097	-5.995
32) 29/08/12 Plt 3 C2	2.351	0.001	1.176	-2.350	69) 12/09/12 NCO C2	5.559	2.909	4.234	-2.651
33) 29/08/12 Plt 4 C2	2.346	0.001	1.173	-2.345	70) 14/09/12 Plt 1	5.495	0.057	2.776	-5.438
34) 29/08/12 NCO C2	1.941	0.004	0.973	-1.938	71) 14/09/12 Plt 2	11.49	0.474	5.981	-11.01
35) 5/09/12 Plt 1 C1	3.967	0.003	1.985	-3.964	72) 14/09/12 Plt 3	12.40	0.007	6.205	-12.40
36) 5/09/12 Plt 2 C1	5.197	0.002	2.600	-5.195	73) 14/09/12 Plt 4	11.98	0.123	6.051	-11.86
37) 5/09/12 Plt 3 C1	6.342	0.002	3.172	-6.340	74) 14/09/12 NCO	9.042	7.465	8.253	-1.578

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